ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

SAFETY PERFORMANCE OF SPEED HUMPS WITH RUMBLE STRIPS IN ADDIS ABABA

BY

TIGIST ESHETU

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for Degree of Master of Science in Civil and Environmental Engineering (Road and Transport Engineering)

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DECLARATION

First, I declare that this thesis entitled with "**Safety Performance of Speed humps with Rumble strips in Addis Ababa**'' is my original work performed under the supervision of my research advisor Dr. Getu Segni. All sources of materials used for the thesis have been properly acknowledged.

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ABSTRACT

With increasing urbanization, vehicle density on the roads has been increasing exponentially. Most of the vehicles and roads are designed for a particular speed. The improved roadway facilities have encouraged the drivers to drive fast in the urban roads. Excessive speed is a key risk factor for road accidents and greater severity of the injuries in the event of an accident. In such circumstances, it is very difficult to control a speeding vehicle unless some speed management measures are provided. In our city Addis Ababa speed calming interventions are implementing on the selected road segments of the city.

The primary aim of this study is to evaluate the safety performance of speed humps with rumble strips in the context of Addis Ababa. To achieve this objective, two types of data were employed: primary and secondary data. Secondary data was utilized to gain insights into the characteristics of accidents on the specific road segments under study. In contrast, primary data was speed survey data, road segment length data and frequency of speed hump (number of speed hump and rumble strips) for the selected road segments. The speed survey data was thoroughly collected using ERA pavement design manual Volume I, 2013 Vehicle classification table. The Secondary data (accident data) covered the years 2014 to 2021 (2006 to 2013 E.C.) and was sourced from the Addis Ababa Police Commission and various sub-city police departments.

The speed survey indicated that 85th percentile speeds were maintained below the speed limits of 30km/h by a considerable percentage at different points along the road segments: 46% 20 m before the speed hump, 92% at the speed hump, and 23% 20 m after the speed hump, across the total selected road segments. The T-test results for Traffic speeds are statistically significant for all variables and for all three pairs except Large Truck on before 20m of speed hump and after 20m of speed hump pair.

Following the implementation of speed humps with rumble strips, the study shown a 31% reduction in Total Equivalent Accidents (EANs), a 24% reduction in total pedestrian accidents, a 54% reduction in pedestrian accidents involving crossing on the roadway, a 2% increase in pedestrian accidents involving walking straight and a 35% reduction in accidents involving public transport vehicles.

Along with T-test results, it can be concluded that speed hump with rumble strips are effective in reducing accidents. When we can see the impact of speed hump with rumble strips on pedestrian safety the results also shows a significant change in the before-and-after study. With respect to pedestrian accidents by main activity speed hump with rumble strips the result also shows a significant change it can be concluded that speed hump with rumble strips are effective in reducing accidents Pedestrians Crossing on Roadway. This affirms that speed hump with rumble strips help in safe Crossing on Roadway. This means pedestrians can Cross relatively easier and are safer than Crossing on the roadway without speed hump with rumble strips.

A T-test carried out on Pedestrians Accident Walking Strait in the before-and-after study indicated no significant change. Using results of this T-test, we can conclude that, speed hump with rumble strips, in this case, do not effect a significant change in reducing Pedestrians crashes Walking Strait. A T-test carried out on public transport study indicated no significant change. Using results of this T-test, we can conclude that, speed hump with rumble strips, in this case, do not effect a significant change in reducing public transport crashes on the road.

Regression analysis used to produce the best relationship between density of speed hump and 85th Percentile Crossing speeds of the vehicles. Generally, the simple linear regression model that include one independent variable (85th Percentile Crossing speed) .The signs of the correlation coefficients in the regression model are as expected. The density of speed hump shows a positive correlation with 85th Percentile Crossing speed.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

ARS	**Amhara Regional State**
BIGRS	**Bloomberg Initiative for Global Road Safety**
DD	**Drink and driving**
DfT	**Department for Transport**
EAN	**Equivalent Accident Number**
ENMTS	**Ethiopia Non-motorised transport strategy**
ERA	**Ethiopian road authority**
GDP	**Gross Domestic Product**
GRSP	**Global Road Safety Partnership**
ITE	**Institute of Traffic Engineers**
NRSCO	**National Road Safety Coordinating Office**
NTCH	**Neighborhood-Traffic-Calming-Handbook**
ORS	**Oromia Regional State**
PEFA	**Public Expenditure and Financial Accountability**
PTCH	**Pennsylvania's Traffic Calming Handbook**
RA	**Roundabout**
RTA	**Road Traffic Accident**
RTF	**Road traffic fatalities**
SSATP	**AfricaTransort Policy Program**
SNNPR	**Southern Nations, Nationalities, and People's Region**
SPSS	**Statistical Package for the Social Science.**
TCRG	**Traffic Calming Resource Guide**
UNECA	**United Nations Economic Commission for Africa**
UNECE	**United Nations Economic Commission for Europe**
WHO	**World Health Organization**
4WD	**Four Wheel Drive.**

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Recently, there has been a yearly increase in the number of fatalities and serious injuries from road traffic crashes. The trends show that road traffic crashes have become a burden of economic, social and health proportions for the country. The Ethiopian Federal Police Commission's report revealed that 2,161 road traffic deaths were registered nationwide in 2007 and this figure more than doubled in 2018, increasing to 4,597 (Federal Police Commission, 2019; cited by UNECE & UNECA, 2020; Federal Police Commission, 2011; cited by UNECE & UNECA, 2020). Moreover, the road fatality estimate made by WHO for Ethiopia, using 2016 figures, was 27, 326(WHO, 2018.) which shows a striking difference from national estimates, and should be addressed.

The level of road crashes is increasing over time with the growth in the number of vehicles, the population, the road network, and the vehicle kilometers driven. The impact of crashes that occurred in the country between July 2013 and July 2021 is as follows: 27,455 fatalities, 33,354 serious injuries and 23,048 minor injuries (Federal Police Commission, 2022). The trends imply that more Ethiopian lives are lost due to road traffic injuries than to other causes. Citizens die on the roads at an average of 4,732 persons per year; or every day, approximately 13 Ethiopians do not return home due to being victims of road traffic crashes. Road traffic injuries in Ethiopia, mostly affect passengers, and pedestrians. In other words, one person is killed on the roads every two hours. It is likely that actual fatality figures in the country are larger than those reported by the Ethiopian Federal Police Commission due to factors such as underreporting and misclassification of road traffic fatalities. An integrated crash database is needed to overcome underreporting road traffic crashes (UNECE & UNECA, 2020).

In Ethiopia the distribution of road traffic crashes is not uniform, for example Ethiopian Police Commission Report, (2006- 2013 E.C) of Fatalities & Serious Injuries by Region/City, 12 months to 30 June shows that out of 12 Regional States and city administration Addis Ababa City Administration, Oromia Regional State and Amhara Regional State ranked from first to third. Those figure shows that most of the time road traffic crashes are concentrated on

Regional State and city administration found in the central part of the country and the Addis Ababa City Administration accounted for almost 85 per cent of the fatalities in the country. Serious injuries have a similar spatial variation among the Regional States, even though the reliability of existing data is compromised by concerns of underreporting and misclassification across the regions. Crash data for three years (2016–2018) shows that consolidated efforts are required in these regions, particularly ORS and ARS. Then, SNNP and Addis Ababa City Administration could be considered to curb the current high level of road death in the country (Road traffic crash data, Ethiopian Police Commission, 2022; Road traffic crash data, Ethiopian Police Commission, 2018; cited by UNECE & UNECA, 2020).

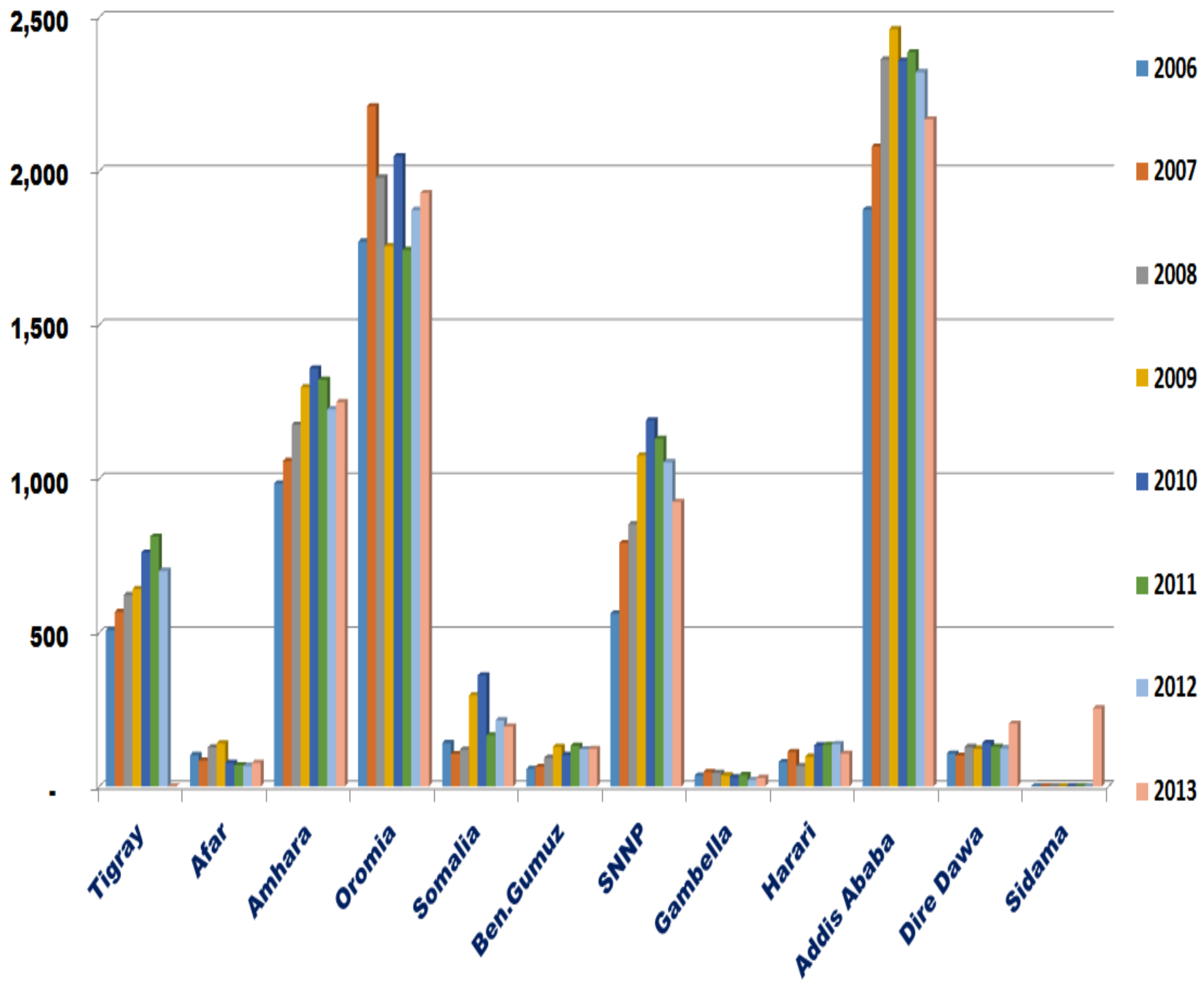

Figure 1- 1: Fatalities & Serious Injuries by Region/City, 12 months to 30 June (Source: Ethiopian Police Commission Report, 2014-2021 G.C (2006- 2013 E.C)

Addis Ababa is experiencing a fast-paced urban sprawl and has eleven counties, called sub-cities. According to the Ethiopian Federal Road Transport Authority 2019; cited by L Kebede, G Tulu, RT Lisinge, 2022, Ethiopia had about 1,071,345 vehicles at the end of June 2019, 56% (about 596,084) of which were registered in Addis Ababa.

Most road crash victims in urban areas are not motor vehicle occupants, but pedestrians. About 33.5 per cent of fatal crashes in the country in 2018 occurred in an urban road environment and mostly involved pedestrians. For instance, in Addis Ababa about 88 per cent of road traffic fatalities are pedestrians (UNECE & UNECA, 2020).

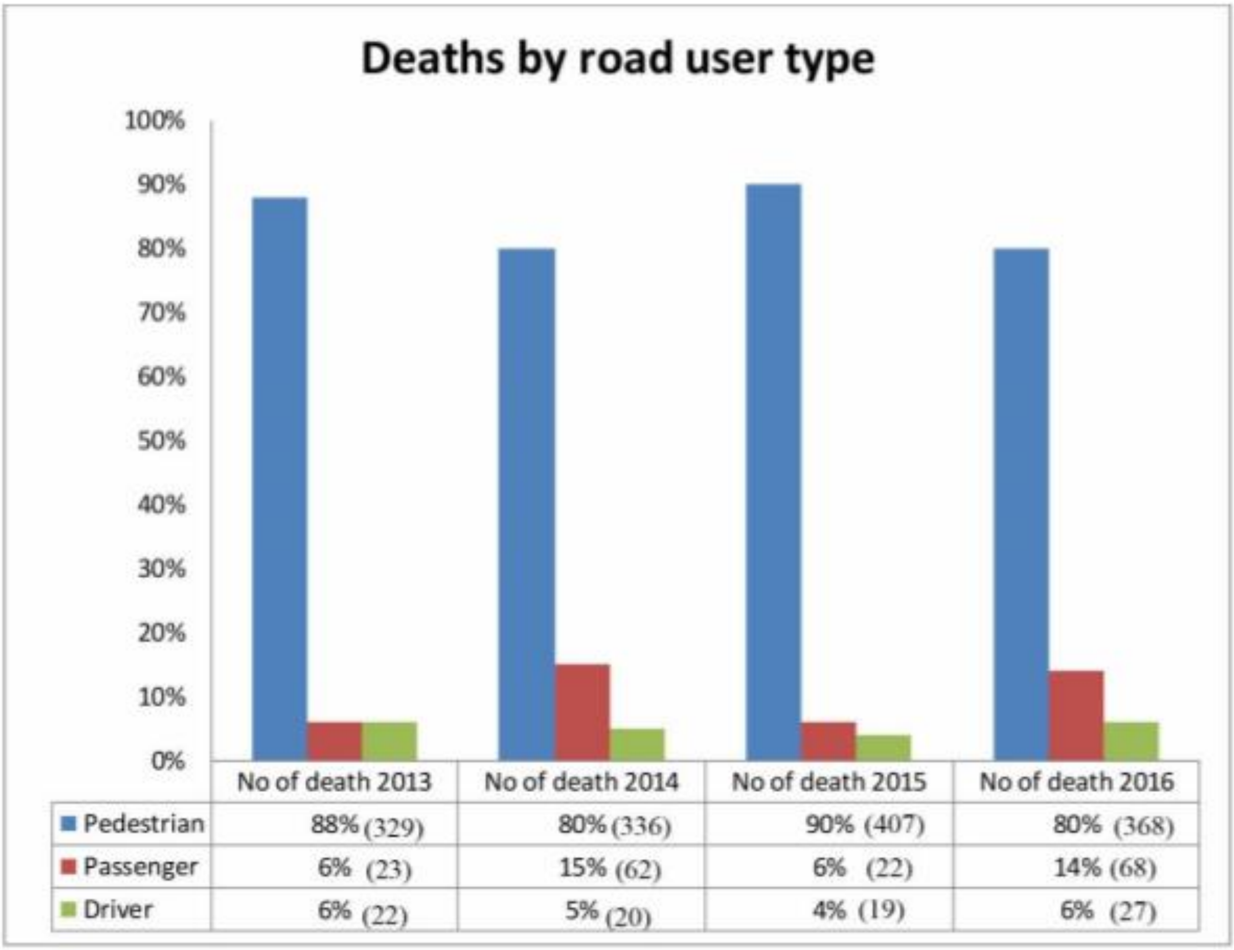

Figure 1- 2: Road Traffic Deaths by road user type in Addis Ababa (Source: Addis Ababa City Road Safety Strategy Implementation Plan (2018-2020))

The main problems in an urban road environment are the absence of adequate pedestrian facilities, excessive speeding, drink driving, inadequate or non-existence of street lighting at night, poor land use planning, as well as the lack of an adequate legal regulatory framework and enforcement of existing laws and regulation (WHO, 2013; WHO, 2009). This has resulted in a rise in the number of road traffic crashes in urban areas (Annual Traffic and Road Safety Report 2019; cited by UNECE & UNECA, 2020, Ethiopian Police Commission, 2019; cited by UNECE & UNECA, 2020).

1.2. Statement of the Problem

The street design in Addis Ababa has undergone transformations that primarily cater to the needs of automobiles, sometimes at the expense of pedestrian safety and convenience. Urbanization has led to a substantial increase in vehicle density on the city's roads, and a significant portion of these vehicles and road infrastructure is designed with a specific emphasis on speed. This design emphasis has inadvertently encouraged drivers to traverse urban roads at high speeds. Excessive speed, as documented by the World Health Organization (WHO, 2015), stands as a key risk factor for road accidents and increase the severity of injuries when accidents occur. In the face of these challenges, controlling speeding vehicles becomes a difficult task without the implementation of effective speed management measures that prioritize safety.

In our city Addis Ababa speed calming interventions are implementing on the selected black spot site of the city to reduce the number of crashes, after those implementation evaluation with repetitive process of research to ensure whether speed calming measures put in place are successful or not, or whether they are resulting any changes at all, there has been a lack of comprehensive research to assess the effectiveness of these measures. This research, therefore, aims to address the safety performance of speed humps with rumble strips, with respect to the equivalent number of accidents reduction in before and after implementation of speed humps with rumble strips, changes in relation to the types of accident involved particularly pedestrians and Furthermore, it assesses the speed reduction of speed humps with rumble strips and relationships of speed hump density and 85th percentile crossing speed.

1.3. Questions for research

This study is designed to systematically collect, analyze, and critically evaluate accident data specific to the city of Addis Ababa. The objective is to weight this data in order to provide comprehensive and informed responses to the following essential questions:

- What is the impact of speed humps with rumble strips on vehicular speeds?
- What is the performance of speed humps with rumble strips on the number of accidents?
- What mathematical model is vital for speed hump density and 85th percentile crossing speed relationship?

1.4. Objectives of the Research

1.4.1. General objective

Examining the safety performance of speed humps with rumble strips in the context of Addis Ababa is the primary goal of the study.

1.4.2. Specific objective

- To conduct descriptive analysis for traffic accidents and speed data.
- To know the impact of speed humps with rumble strips on vehicular speeds.
- To evaluate the performance of constructed speed humps with rumble strips with respect to accident reduction.
- To develop a mathematical model for speed hump density and 85th Percentile Crossing speed relationship.

1.5. Scope of the study

The goal of the study is to assess Addis Ababa's speed calming program's safety effectiveness in relation to the goals of the measures that have been put in place there. The following issues are the limits of the research scopes:

- The research is executed on selected roads of Addis Ababa, specifically which have both speed humps and Rumble Strips constructed from July 2009 E.C to June 2010 E.C.

1.6. Significance of the Research

The study's findings hold significant implications on both theoretical and practical fronts. Theoretical importance lies in the provision of critical data for road safety experts. It furnishes them with a comprehensive understanding of the dynamics of traffic crashes before and after the implementation of speed calming measures, offering insights into the evolution of accident patterns, particularly those involving pedestrians.

On a practical level, the research carries implications of paramount importance. It serves as a valuable tool in evaluating the effectiveness of speed calming measures on road safety improvement within the context of Addis Ababa, offering a tangible basis for decision-making by local authorities. The findings can guide authorities in determining whether to continue employing Speed humps with Rumble strips as a traffic calming measure or explore alternative solutions. Additionally, the research results can be instrumental in shaping policies related to traffic calming in the city, contributing to safer roadways. Furthermore, the information and data generated by this research serve as a foundation for future studies, providing a resource for researchers to replicate and extend the frontiers of knowledge in this critical domain of road safety.

1.7. Organization of the Research

There are five chapters in this research.

First Chapter provides a concise synopsis of the study's background, problem statement, research question, general and particular objectives, study scope, research importance, and research organization.

Second chapter focuses on the review of literature on Speed control measures, Speed Calming Effectiveness in the international context (Speed Calming Effectiveness on Travel Speed reduction and Speed Calming Effectiveness on Accident reduction), Intervals along with corresponding speeds, Local Studies and Gaps and summary of the reviewed research.

Third Chapter outlines the materials, techniques, and research methodologies used, as well as the subject area, Research design, Sampling method, Methods of data collection and Method of data investigation.

The fourth chapter provides the study's findings and a discussion of them.

The Fifth Chapter addresses recommendations and conclusions. The results of this study were wrapped up in this chapter.

CHAPTER TWO

LITRATURE REVIEW

2.1. Speed control measures

Speed control measures are primarily used to address speeding problems by changing vertical alignment, changing horizontal alignment, or narrowing the roadway. Those Speed control measures are Vertical Deflections ,Speed Cushion, Raised Intersection, Speed Table, Raised Crosswalk, Rumble Strips, Speed hump, Horizontal Deflection, Neighborhood Traffic Circle, Roundabout, Chicane, Realigned Intersection and Tight Radii. But this study focused on speed humps and rumble strips in particular.

a) Speed hump

Speed humps are raised areas placed across the roadway Deflecting both the wheels and frame of traversing vehicles. They are often tapered as they reach the kerb on each end to allow unimpeded drainage. Speed Humps are good for locations where very low speeds are desired and reasonable, and where noise and fumes are not a major concern. Typically Uses Within typical residential travel speeds, humps create a gentle rocking motion encouraging motorists to slow to a safe speed at or below the speed limit. (M.Vanderschuren & R.Jobanputra, 2009; PTCH, 2012).

b) Rumble Strips

Rumble strips are raised buttons or grooves closely spaced on roadway surface to create noise and vibration. They are typically installed to alert drivers of an upcoming curve or speed change. It is also patterned sections of rough pavement or topical applications of raised material, which when driven over cause vibration and noise in a vehicle. This treatment is intended to direct the attention of the motorist back to the roadway (NTCH, 2018; TCRG, 2008).

Generally, there are three types of rumble strips that based on the location of its installation i.e., 1) shoulder rumble strips 2) centerline rumble strips and 3) transverse rumble strips. Shoulder rumble strips are placed on roadway shoulders, outside of the travel lane. The purpose of shoulder rumble strips is mitigating single vehicle run-of-road type crashes. Centerline rumble strips are installed on or near centerline of roadway. The purpose is to mitigate head-on crashes and opposite direction sideswipe crashes. Transverse Rumble strips are placed across the travel lanes of the roadway and perpendicular to flow of vehicles. TRS is basically intends to alert drivers only through the effect of tactile and audible. Therefore, it is assumed that by only through TRS vibration and noise sensation, drivers would become alert. This item is compatible with the definition of the Transportation Association of Canada (TAC) which describes TRS as a “lateral pattern of grooves or raised pavement material that vertically deflects wheels of a vehicle driving over them thereby producing both noise and vibration” (Mohd Hanifi Othman , Zaiton Haron, Mohd Rosli Hainin, Khairulzan Yahya, Haryati Yaacob and Mohd Erwan Sanik,2015).

2.2. Speed Calming Effectiveness in the international context

2.2.1. Speed Calming Effectiveness on Travel Speed reduction

Speed is a fundamental factor at the core of road accidents, given that the greater the speed, the shorter the available time to react and prevent a collision, and the more severe the impact in the event of a collision. In the context of road safety, speed-related issues are often categorized into two distinct concepts. Excess speed is specifically defined as exceeding the established speed limit, constituting a violation of legal regulations. In contrast, inappropriate speed refers to driving at a rate that is unsuitable for the prevailing road and traffic conditions. It's important to distinguish between these two categories, as a speed limit merely sets the upper legal speed threshold, while it remains the responsibility of each driver to assess and determine the appropriate speed within that limit, taking into account the specific conditions they encounter on the road (Hamdy Faheem, 2012). This differentiation highlights the significance of both adhering to speed limits and adjusting driving speed in accordance with the current environment to promote road safety.

A significant body of literature strongly supports the idea that there exists a clear and positive correlation between a vehicle's impact speed and the likelihood of pedestrian fatalities. Research findings consistently indicate that when a vehicle collides with a pedestrian at lower speeds, the probability of injury and the risk of fatality are notably reduced. For instance, at a speed of approximately 20 km/h, the likelihood of a fatality resulting from such an incident is estimated to be around 5%, as documented by studies like those conducted by Rosen and Sanders in 2009 and Berthod and Leclerc in 2013. In contrast, this probability of fatality experiences a substantial increase as vehicle speeds rise, particularly within the range of 40 km/h to 60 km/h. If a vehicle is traveling at a speed of 60 km/h, the probability of a pedestrian dying as a result of the collision soars to approximately 90%. This critical relationship is visually illustrated in Figure 2.1. Building on this theory, if speed humps, as a traffic calming measure, effectively succeed in reducing vehicle speeds (regardless of their impact on the overall accident rate), it can be reasonably inferred that any collisions occurring in areas where speed humps are installed would typically transpire at lower speeds. Consequently, when such crashes occur at reduced speeds, it can be logically concluded that speed humps play a pivotal role in mitigating the severity of injuries and diminishing the likelihood of pedestrian fatalities stemming from these accidents.

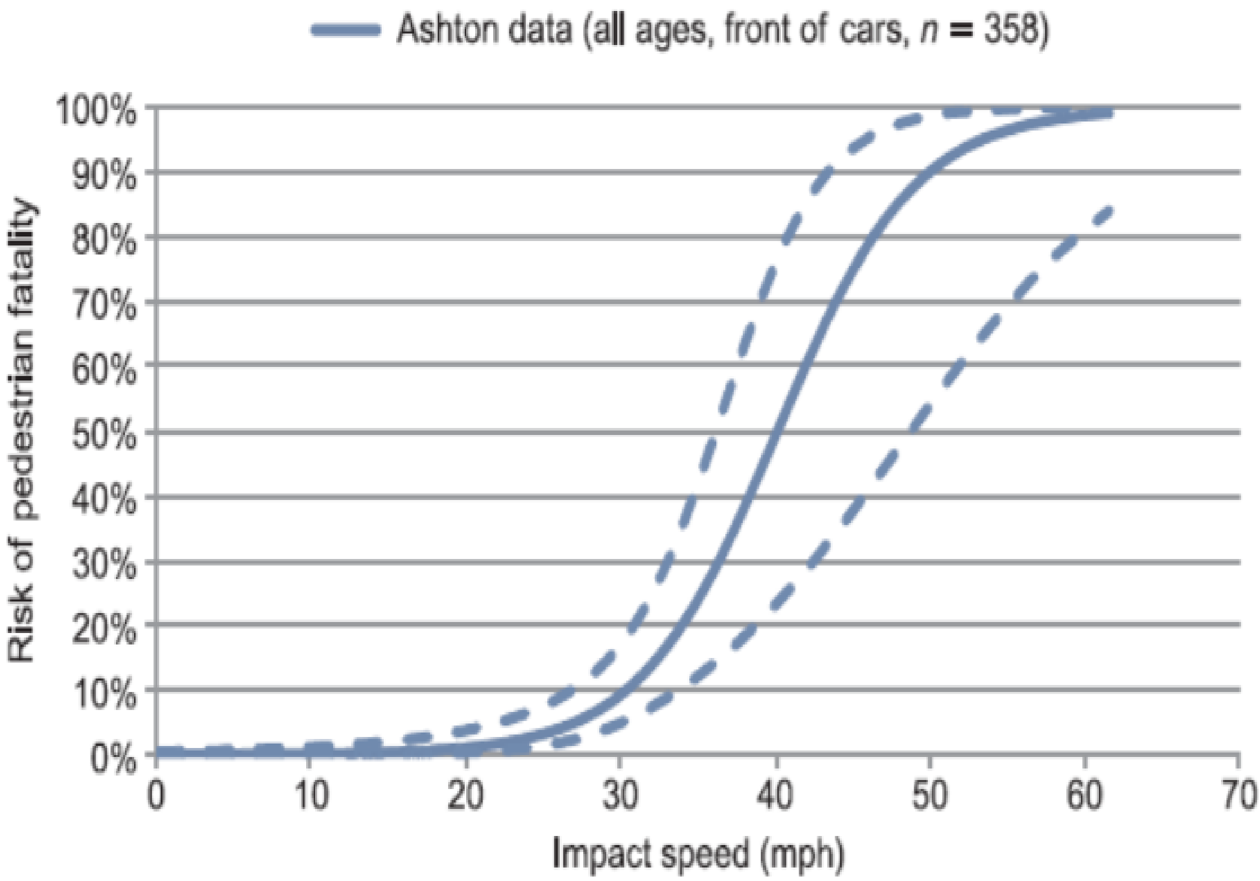

Figure 2 - 1: Likelihood of pedestrian fatality, according to impact speed (Source: Department for Transport: London, 2010)

The primary objective of speed humps is to reduce vehicle speeds. An analysis of multiple studies reveals that the extent of speed reduction is influenced by various factors such as the design and spacing of the speed humps, the surrounding environment, and the types of vehicles using the road. Additionally, the effectiveness of speed humps can differ based on the speed limit in place and the specific dimensions of the speed humps, including their height and width. To assess the impact of speed humps on speed behavior, speed profiles were generated to evaluate vehicle speeds as they approached, traversed, and departed from these traffic calming devices. This in-depth analysis provides valuable insights into the effectiveness of speed humps in achieving the intended reduction in vehicle speeds and enhancing road safety.

In general, speed humps are often considered self-regulating and are colloquially referred to as "sleeping police officers." Numerous studies have demonstrated the effectiveness of road humps in slowing down vehicles as they pass through a particular area, particularly in the immediate vicinity of these devices. In typical scenarios, drivers approaching a speed hump tend to decrease their speed to avoid a bumpy ride, consequently reducing the likelihood of speed-related accidents that might occur otherwise. Following their passage over a hump, drivers often accelerate once again (C. Parsuvanathan, 2016).

Earlier research findings suggest that the use of transverse rumble strips leads to a modest reduction in vehicle speeds, typically in the range of 1.6 to 6.4 kilometers per hour (1 to 4 miles per hour). Some observations from specific locations indicated that, in the aftermath of installing these strips, post-implementation speeds showed a slight increase over time but remained below the pre-installation speeds (Paul J. Carlson, Mark W. Burris, and Tyrell D. Thompson 1973; DfT, 2007).

Table 2-1: Summary of the Literature on impact of Speed Calming on travel Speed

Speed calming measure	**Case study**	**Results and Effectiveness**	**Reference (Authors)**
round-top and flat top road humps (Speed Hump)	Main campus of Universiti Teknologi Malaysia (UTM)	Based on the analysis, the reduction in mean speed for the round-top road hump was around 46%, while for the flat-top road hump, it was around 52%. Therefore, the findings clearly showed that well designed road humps are effective at reducing speeds on local roads at the main campus area of UTM.	Nordiana Mashros, Muhammad Faizudin Md Nor, Aztri Yuli Kurnia, Sitti Asmah Hassan, Norhidayah Abdul Hassan, Nor Zurairahetty Mohd Yunus, (2020)
Humps, Bumps and Speed tables	Ghana	The mean speed on traffic calming measures generally ranges from 9 km/h to the highest of 27 km/h on speed calming measures. The predominant TCMs along the road corridor were speed bumps. Though speed bumps are smaller than humps and tables, their speed reducing capabilities are the most drastic. This is due to the unforgiving angles that speed bumps have on motorists compared to humps and tables,	James Damsere-Derry, Richard Lumor, Shaibu Bawa and David Tikoli, (2020)
Modified signs, Peripheral marking, Continuous rumble (a transverse rumble strips) and Hatched design	North of Iran	Based upon the results obtained, all TCMs significantly decreased the amount of traffic's mean speed (km/h). Modified signs (reduction from 83.29 to 63.10), Peripheral marking (reduction from 83.29 to 63.97), Continuous rumble (a transverse rumble strips) (reduction from 83.29 to 61.39) and Hatched design (reduction from 83.29 to 61.13).	A. Akbari, F. Haghighi / IATSS Research, (2020)
Speed hump	International Islamic University Malaysia (Malaysia)	Based on the findings, the average speed of vehicles for these three road humps (Road Hump 1, Road Hump 2 and Road Hump 3) after passing the road hump were higher than the average speed of vehicles before approaching the road hump except for cars at Road Hump 3. Besides, from the average speed, all types of vehicles travelled within the speed limit at all road humps except for motorcycles at Road Hump 3 which travel above the speed limit (30.27 km/h).	Nur Asiah MUSTAFA, Abdul Azeez KADAR HAMSA, (2019)

Speed hump	EThekwini Municipality in South Africa	The results of the survey proved that speed humps are effective in slowing down vehicular speeds. In the study, 85^{th}percentile speeds were kept all below the design speeds of 40km/h.	Lemohang Monyatsi, (2019)
Speed tables, speed humps and speed bumps	Ghana	Travelling higher than the speed limits were generally greater in such towns without any traffic calming devices compared with those with traffic calming measures. This research shows that between 60% and 100% of drivers typically travel above the mandatory 50 km/hour speed limit in settlements there are no traffic calming devices.	James Damsere-Derry, Beth E. Ebel, Charles N. Mock, Francis Afukaar, Peter Donkor, Thomas Ojo Kalowole, (2019)
Speed humps and speed cushions	Sweden and Israel	a placement of speed humps in the range of 20 to 10 m before the crosswalk support ‘ideal interactions’ from the point of view of the pedestrian; and children crossing receive a stronger message about whether drivers intend to stop or not.15 cm trapezoidal speed hump at the crosswalk, Mean speeds of 25–30 km/h. and 8–10 cm circular humps 15–20 m before the crosswalk, 85% speeds of 30–38 km/h (reductions of 20–30 km/h, in both indicators).10–12 cm trapezoidal speed hump at the crosswalk, Mean speeds of 33–37 km/h and 6–8 cm circular humps 15–20 m before the crosswalk, 85% speeds of 40–44 km/h (reductions of 10–15 km/h, in both indicators). When the speed cushion is situated at a longer distance from the pedestrian, drivers are more aware of the approaching pedestrian crossing as they then get more time to focus on approaching pedestrians and cyclists after passing the speed cushion.7–10 cm speed cushions 8–10 m (Hultag, 5 m) before the crosswalk, Mean speeds of 22 km/h, 90% speeds of 27–28 km/h.7–10 cm speed cushions 4–5 m (Hultag 3 m) before the crosswalk, Mean speeds of 23–24 km/h, 90% speeds of 30 km/h.	Lars Leden, Charlotta Johansson, Peter Rosander, Victoria Gitelman and Per Gårder, (2018)

Speed hump and gateway (speed humps of trapeze shape and a raised pedestrian crossing)	Lithuania in Europe	Research on the Mean vehicle speed determined that on a 1.6 km long road section six vertical traffic calming measures do not ensure compliance with the speed limit in the urban area (50 km/h). Fifty-eight percent of drivers exceeded the speed limit by less than 10 km/h, and 17% – by more than 10 km/h. A high percentage of drivers exceeding the speed limit by less than 10 km/h can be affected by the Code of Administrative Offences of Lithuania, which provides that the drivers exceeding the speed limit by less than 10 km/h are given only a verbal warning but not a financial penalty.	Audrius Vaitkus, Donatas Čygas, Vilma Jasiuniene, Laura Jateikiene, Tadas Andriejauskas, Dovydas Skrodenis and Kornelija Ratkeviciute,(2017)
		The mean speed data from the selected roads with trapeze shape speed humps declined no compliance with speed limit. Within the urban area, 74.12% of drive r s speed up f r o m 17 k m/h to 44 km/h above the speed limit. Within the distance of 120 m behind the speed hump, the permitted speed of 50 km/h is violated and at the distance of 190 m the speeding is above 10 km/h.	
		Research on the instantaneous vehicle speed has found that 300 m distance between two speed humps of trapeze shape is too large to ensure compliance with the speed limit. Research results showed that in the urban area the speed limit is already exceeded 120 m behind the speed hump and at a 200m distance behind the speed hump, the speed limit is exceeded by 10 km/h or more.	
		The collected traffic speed data lead to the conclusion that the gateways are efficient, but still, the permitted speed of 50 km/h is not ensured in all cases. As the main parameter of gateway efficiency, the width and length of the island should be indicated, as it very much affects the visual “enframing” of road traffic lanes.	

Speed hump with passage one-way narrowing and U-turn, Central Island in pedestrian crossing (pedestrian Passage), speed hump with passage two-way narrowing (with U-turn), and speed dump.	Hamedan city, Iran	Calming measures S1 (speed hump with one way narrowing passage) and S3 (speed hump with two-way narrowing passage) caused a higher speed reduction in vehicles given their geometric conditions.	Hamid Shirmohammadi, Esfandiar Mardani, Majid Emdadian Ghane and Araz Hasheminezhad, (2017)
		A highest standard deviation was observed in calming area S2 (central island in pedestrian crossing), in which drivers generally reduced their speed only when pedestrians were passing.	
		Average speeds of scenarios varied between 43.019 km/h and 47.8346 km/h, which is an indication of the effect of TCMs on average speed reduction of vehicles. This speed reduction varied due to the number and spacing of the measures.	
Transverse Bar (Transverse Rumble Strip)	Malaysia	Speed of the vehicles decreased when vehicles approached Transverse Bar A. but not in the case of Transverse Bar B. the design profile of Transverse Bars at A is similar to that of at B. However, the location of Transverse Bar B is very close to vertical curve.	Nur shuhadah MOHD and Abdul Azeez KADAR HAMSA, (2017)
Transverse Rumble Strip	US 280 in Alabama	The tested TRS showed positive effects on speed reduction. The statistical analysis revealed that except for the Salem daytime condition, speed reductions by all the tested TRS were statistically significant at a 95% confidence level comparing upstream, before TRS, and after TRS locations. The overall speed reduction was 3 to 5 mph for a green light ahead and had an increase of 3 mph when the red light was visible.	Lingling Yang, Huaguo Zhou, Lingxi Zhu and Hongyang Qu, (2016)
		The TRS has certain effects on driver behavior on braking. Some unsafe behaviors were not observed, such as intensive deceleration in front of the strips or moving partly onto the shoulders to avoid the TRS.	

Speed hump	Egypt	The used speed humps reduce the speed in all cases to less than 20 km/hr which considered very high reduction on this class of highways. Speed humps caused excessive drop in speed at the humps, the drop in speed reaches an average of 75 % of the normal speed.	Hamdy Faheem, (2012)
Transverse Rumble Strip	China	With speed limits of 60 km/h and 80 km/h, transverse rumble strips are effective in reducing vehicle speeds in vicinity of pedestrian crosswalks. The speed reduction effects at selected sites vary from 3.1 km/h to 16.9 km/h. On average, the mean speed declined 9.2 km/h on roads with a speed limit of 60 km/h; and 11.9 km/h on roads with a speed limit of 80 km/h. The 85th percentile speed declined 9.1 km/h on roads with a speed limit of 60 km/h; and 12.0 km/h on roads with a speed limit of 80 km/h.	Pan Liu, Jia Huang, Wei Wang and Chengcheng Xu, (2011)
		The influence area of transverse rumble strips is generally less than 0.3 km. Drivers at selected sites start to decelerate vehicle speeds at about 120 m ahead of pedestrian crosswalks or about 20 m before the most upstream set of transverse rumble strips. The lowest average speed was achieved at the location where the last set of transverse rumble strips was deployed. After passing the transverse rumble strips, drivers start to accelerate vehicle speeds and vehicle speeds are usually recovered within 100 m after pedestrian crosswalks.	

2.2.2. Speed Calming Effectiveness on Accident reduction

The primary objective of investing in safety measures on roadways is to create safer environments for all road users, with a particular focus on reducing the number of accidents and minimizing the severity of those accidents. In pursuit of this goal, numerous researchers have undertaken comprehensive studies to assess the effectiveness of various safety measures, including speed calming interventions. These studies aim to provide valuable insights into how speed calming measures can effectively reduce the incidence of accidents, ultimately contributing to enhanced road safety and the well-being of individuals who travel on these roadways.

Table 2-2: Summary of the Literatures on the outcome of Speed Calming on Accident

Speed calming measure	**Case study**	**Results and Effectiveness**	**Reference (Authors)**
Humps, Bumps and Speed tables	Ghana	Pedestrian fatalities still constitute 34% of all casualty deaths and 14% of total casualty injuries.	James Damsere-Derry, Richard Lumor, Shaibu Bawa and David Tikoli, (2020)
Speed hump	EThekwini Municipality in South Africa	The equivalent number of total accidents was reduced by 20% after implementation of speed humps.	Lemohang Monyatsi, (2019)
		Accident amongst young pedestrians the number went from 30 to 5.	
		In communities where there is inadequate NMT facilities such as sidewalks? From the results, there was a reduction in the number of pedestrians.	
		There were 103 public transport vehicles (busses and minibus taxis) involved in crashes before speed humps were installed and this dropped to 66 vehicles after speed humps were implemented, a reduction by 35.92%.	
Speed tables, speed humps and speed bumps	Ghana	If a pedestrian is involved in a crash in settlements which have no traffic calming devices, it is twice as likely to result in a fatality compared with crashes in towns where traffic calming schemes were present. Seventy-six (76) pedestrian casualties constituting (38%) of the pedestrians' casualties occurred in settlements which have traffic calming schemes whilst 124 number casualties representing 62% of the total pedestrian casualties in the study coincided with settlements which have no traffic calming schemes.	James Damsere-Derry, Beth E. Ebel, Charles N. Mock, Francis Afukaar, Peter Donkor, Thomas Ojo Kalowole, (2019)

Speed hump	EThekwini Municipality in South Africa	Pedestrian casualties 17% reduction (from 588 to 490) and 44% reduction (from 172 to 97) in Chatsworth and KwaMashu, respectively.	N Nadesan-Reddy, S Knight, (2013)
		Serious pedestrian-vehicle collisions, involving children (under 19 years of age), decreased by 39% (from 168 to 102) and by 33% (from 52 to 35) in Chatsworth and KwaMashu, respectively.	
		The number of deaths decreased from 22 to 7 in Chatsworth and from 2 to 1 in KwaMashu.	
		Serious pedestrian-vehicle collisions (PVCs) dropped by 23% and 22%, while fatal collisions decreased by 68% and 50% in Chatsworth and KwaMashu, respectively.	
Transverse Rumble Strip	China	Transverse rumble strips are effective in reducing crashes in vicinity of pedestrian crosswalks on rural roads. Results of the EB before-after study show that the deployment of transverse rumble strips may reduce expected crash frequency in vicinity of pedestrian crosswalks by 25%. The standard deviation associated with this estimate is 24%.	Pan Liu, Jia Huang, Wei Wang and Chengcheng Xu, (2011)

2.3. Intervals for Speed Reading

The speed reading points used by various researchers in this field vary, and they subsequently draw conclusions on the efficacy of speed-calming techniques in reducing speed.

Table 2-3: Summary of the Literature on intervals (change in distance) for spot speed survey

Speed calming measure	Case study	Points at which Speed reading was taken	Reference (Authors)
round-top and flat top road humps (Speed Hump)	Main campus of University Technology Malaysia (UTM)	50m before hump	Nordiana Mashros, Muhammad Faizudin Md Nor, Aztri Yuli Kurnia, Sitti Asmah Hassan, Norhidayah Abdul Hassan, Nor Zurairahetty Mohd Yunus, (2020)
		On hump	
Humps, Bumps and Speed tables	Ghana	Between humps	James Damsere-Derry, Richard Lumor, Shaibu Bawa and David Tikoli, (2020)
		On hump	
Speed hump	International Islamic University Malaysia (Malaysia)	20 meters before the Road Hump	Nur Asiah MUSTAFA, Abdul Azeez KADAR HAMSA, (2019)
		at the Road Hump	
		20 meters after the Road Hump	
Speed hump	EThekwini Municipality in South Africa	37.5 m - From hump 1	Lemohang Monyatsi, (2019)
		75m-Midpoint	
		112.5m -Towards Hump2	
Speed hump and gateway (speed humps of trapeze shape and a raised pedestrian crossing)	Lithuania in Europe	119 m behind the first hump	Audrius Vaitkus, Donatas Čygas, Vilma Jasiuniene, Laura Jateikiene, Tadas Andriejauskas, Dovydas Skrodenis and Kornelija Ratkeviciute,(2017)
		189 m behind the first hump	
		at a distance of 62 m before the second hump	
		50 m before the gateway	
		Beside the gateway	
		50 m behind the gateway	

Speed hump with passage one-way narrowing and U-turn, Central Island in pedestrian crossing (pedestrian Passage), speed hump with passage two-way narrowing (with U-turn), and speed dump.	Hamedan city, Iran	30m before	Hamid Shirmohammadi, Esfandiar Mardani, Majid Emdadian Ghane and Araz Hasheminezhad, (2017)
		30m after	
Transverse Bar (Transverse Rumble Strip)	Malaysia	50 meters before the Transverse Bar	Nur shuhadah MOHD and Abdul Azeez KADAR HAMSA, (2017)
		at the Transverse Bar	
		50 meters after the Transverse Bar	
Transverse Rumble Strip	US 280 in Alabama	The upstream locations in advance (122 m) of the Transverse Rumble Strip	Lingling Yang, Huaguo Zhou, Lingxi Zhu and Hongyang Qu, (2016)
		before the Transverse Rumble Strip	
		after the Transverse Rumble Strip	

2.4. Local Studies

Mewded S. (2020) conducted a study to assess the impact of speed hump construction on traffic crashes. The research focused on various road segments, including Sidest Kilo to Afinchober, Betel RA to Keranyo RA, Aware RA to Balderas Condominium, Bisrate Gebrel to Abo RA, Kara to Wesson, Anfo RA to Keranyo RA, and Ayer Tena to Jemo Michel. The study found that the total number of traffic crashes decreased significantly in these areas, with reductions of 52%, 47.6%, 41.3%, 43%, 42%, 36%, and 58%, respectively. To evaluate the reduction in traffic crashes, data related to motorist crashes before and after the construction of speed humps were collected for the period from 2009 to 2012 E.C, corresponding to the construction period. The study also assessed the 85th percentile speed at the selected speed humps, which efficiently reduced speeds to a range of 22 km/hr to 24 km/hr. As a result, the posted speed limits were found to be acceptable for the respective road segments, with limits of 30 km/hr for Sidest Kilo to Afinchober, Aware to Balderas Condominium, Betel RA to Keranyo RA, Bisrate Gebrel to Abo RA, Kara to Wesson, and Anfo RA to Keranyo RA, and a limit of 50 km/hr for Ayer Tena to Jemo Michel. The study collected spot speed data at three specific points: 50m before the speed hump, at the speed hump, and 50m after the speed hump, using Laser Technology.

Mershaye W. (2022) conducted a speed analysis study, and the results indicated that the average maximum speed for all vehicle groups reduced by 32.61% as they approached the speed humps within the range of 25 meters to 5 meters. To assess the impact of the speed humps on vehicle speed, the study collected spot speed data at various points upstream of the installed speed humps, specifically at distances of 25 meters, 20 meters, 15 meters, 10 meters, and 5 meters approaching the next speed hump. This data collection helped evaluate how the speed humps influenced the speeds of different vehicle groups.

2.5. Gaps and summary of the reviewed research

Previous research on speed calming primarily focused on vehicle speed reduction at various locations around speed humps without considering the impact of speed humps on different types of vehicle classifications. However, the current study takes into account this scenario, examining how different types of vehicles are affected.

Regarding the total traffic crash reduction, there are some important considerations. The base period for data collection is not clearly specified, which is crucial for properly assessing the before and after implementation data. The study was conducted over a relatively short period, which might not be sufficient to draw definitive conclusions. Further research is required to delve deeper into this area. To improve the reliability of the results, the current study made modifications to the data collection method used in previous research. It collected consecutive road crash statistics from the seven most recent years, spanning from 2014 to 2021 (or 2006 to 2013 E.C), ensuring that a three-year period before implementation and a three-year period after the implementation were considered. This approach helps eliminate potential one-year anomalies that could distort the results.

However, it's worth noting that previous studies have some shortcomings in their analysis of crash data, particularly in the way they portray total traffic crash reduction. This portrayal tends to overstate the actual reduction, as a closer look at the annual traffic accident data for Addis Ababa city reveals that accidents haven't decreased significantly. Furthermore, these studies fail to identify potential anomalies that might impact road safety conditions and, consequently, the study's findings. In contrast, the current research takes a more comprehensive approach to analyze crash data. It delves into various crucial aspects, such as changes in the total number of accidents, alterations in total pedestrian accidents, shifts in pedestrian accidents occurring while crossing roadways, modifications in pedestrian accidents involving pedestrians walking straight, and adjustments in accidents involving public transport vehicles. Additionally, this study examines the relationships of speed hump density and 85th percentile crossing speed.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Description of Study Area

This study was conducted in Addis Ababa which is located in the central highlands of Ethiopia between 80 48’ and 90 6’ North latitudes and 380 38’ and 380 54’ East longitudes. It is situated at the western margin of the Great East African Rift Valley at 2,100–3,000 m altitude, and it is the third highest capital city in the world with a subtropical highland climate. It is the political and cultural center of Ethiopia, and the African Union and the Economic Commission for Africa are based in Addis Ababa. Nowadays, it is also serving as a center for many international organizations and is becoming a city of the African nations with regard to economic, social, and political life. The land area of Addis Ababa is 540 km2 and is surrounded by Oromia special zones (Sheger city). The total population of Addis Ababa is estimated to be 3.6 million according to the projection of the Central Statistics Agency as of GC 2017 (PEFA, 2019). The city is also a commercial hub of the country. With the rapid economic growth of the country during the past couple of decades, the city has also shown dramatic growth in all perspectives. It is 10 times the second biggest city in terms of population, and it is the only city in the country with a population of more than a million. More than 60 per cent of vehicles in the country are registered in the city (Africa Regional Workshop, 2018).

The city’s growth was accompanied with road traffic fatalities growth until recently. The City implement different Interventions to reduce fatalities and serious injuries through the support of Bloomberg Initiative for Global Road Safety (BIGRS).Since the start of its implementation, the following major interventions have been initiated: Like Drink and driving (DD) campaign, Speed control campaign, Improvement of locations with more than 3 yearly fatalities(Speed humps Construction with Rumble strips, fencing and bollard installation), Pedestrian walkway maintenances and construction, Maintenance and installation of street lights and other road safety improvements (Africa Regional Workshop,2018). But this research mainly focused on safety performance evaluation of speed calming (Speed humps with Rumble strips) interventions in Addis Ababa city.

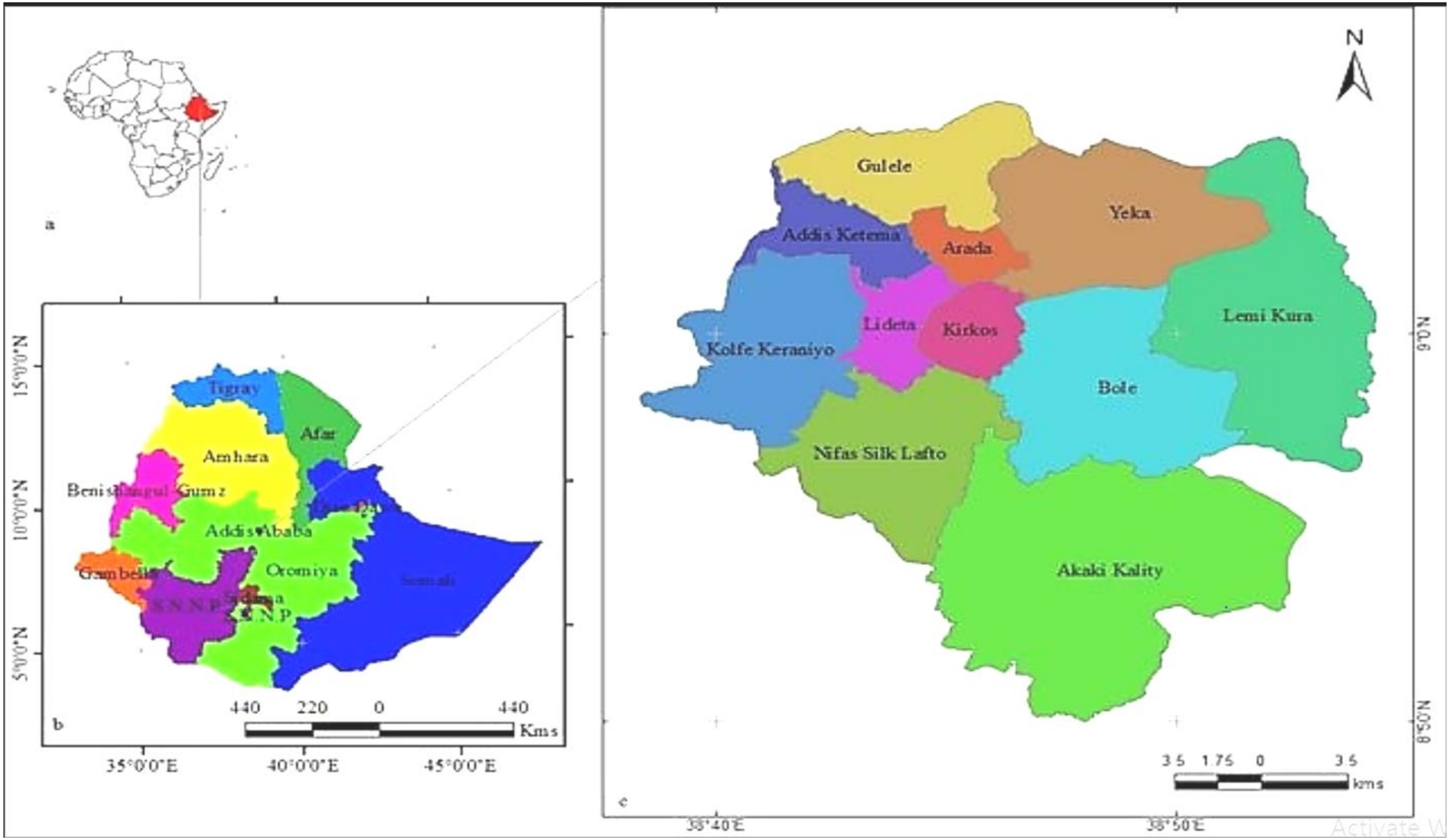

Figure 3 - 1: Location of Addis Ababa in Ethiopia and Map of Addis Ababa including Administrative Sub Cities (Source: Google).

3.2. Research design

The research methods have been meticulously tailored to address the specific research questions and facilitate informed conclusions regarding the safety performance of Speed humps with Rumble strips. To answer the question of the impact of these measures on vehicular speeds, a comprehensive speed survey will be conducted. This survey will encompass various locations around the Speed humps, allowing for the measurement of variations in vehicle speeds.

For the question pertaining to the performance of Speed humps with Rumble strips in reducing the number of accidents, injuries, and fatalities, a before-and-after study will be employed. This study will compare accident data before the implementation of Speed humps with Rumble strips to the post-implementation period, providing valuable insights into the impact of these measures on road safety. Initially, this analysis will be conducted at an aggregated level, utilizing Equivalent Accident Numbers (EANs), and subsequently, it will be disaggregated to explore other relevant indicators, as detailed in Section 4.2 of the research. Lastly, to address the question to developing a mathematical model for speed hump density and 85th Percentile Crossing speed relationship.

3.3. Sampling method

The research focused on evaluating the safety performance of speed humps equipped with rumble strips in the urban setting of Addis Ababa, as outlined in the preceding sections of this paper. Specifically, the study concentrated on road segments where these speed humps with rumble strips had been deployed. Based on available data sourced from the Addis Ababa City Administration Traffic Management Agency, a total of 42 road segments had these speed humps with rumble strips implemented up to July 2020 G.C (or June 2012 E.C). These road segments were categorized into three distinct groups based on their implementation periods. There were 13 road segments that were implemented from July 2017 to July 2018 (or from July 2009 to June 2010 E.C), 17 road segments from July 2018 to July 2019 (or from July 2010 to June 2011 E.C), and 12 road segments from July 2019 to July 2020 (or from July 2011 to June 2012 E.C).

In order to establish a reliable reference period for conducting a three-year before-and-after implementation study, one group was randomly selected. This group comprises the road segments implemented from July 2017 to July 2018 (or from July 2009 to June 2010 E.C). The rationale behind this choice was to ensure the study's results are robust and trustworthy. The research encompasses all road segments constructed during this specific period, thereby providing a comprehensive and statistically sound basis for assessing the impact of speed humps with rumble strips on road safety in Addis Ababa.

Table 3.1: Selected Road Segments of the study

Road segments	**No. of Speed hump**	**No. of rumble strip**	**Speed Limit (Km/hr)**	**implementation period**
Bethel RA-----Keranyo RA	9	13	30	May 2010 E.C
Anfo RA-----Keranyo RA	6	10	30	May 2010 E.C
Mendida intersection---Tor hayloch	12	17	30	May 2010 E.C
Lideta interchange---AU Junction (LidetaTsebel)	3	2	30	May 2010 E.C
Mekanisa Abo RA---Mekanisa bridge	2	1	30	May 2010 E.C
BisrateGebriel-----Mekanisa Abo RA	7	10	30	May 2010 E.C
Lideta Condominium-----Lideta interchange	3	3	30	June 2010 E.C
Semen hotel signalized intersection--Afinchober	2	4	30	April 2010 E.C
Balderas condominium----Aware RA	3	3	30	April 2010 E.C
Parlama signalized intersection-----Aware RA	3	6	30	April 2010 E.C
KokebeTsibah secondary School----Kebena RA	2	2	30	April 2010 E.C
Minilik II hospital-------Kebena RA	2	5	30	April 2010 E.C
6 kilo RA--Afinchober	2	5	30	April 2010 E.C

Figure 3-2: Location Map of Selected Road Segments

3.4. Methods of data collection

To achieve the study's objectives, a combination of primary and secondary data was utilized. Secondary data was gathered to gain insights into and identify the accident characteristics of the specific road segments under investigation. Primary data includes speed survey data, road segment length data and frequency of speed hump (number of speed hump and rumble strips) for the selected road segments.

3.4.1. Primary Data

3.4.1.1. Spot speed Survey

Spot speed studies are conducted to estimate the distribution of speeds of vehicles in a stream of traffic at a particular location on a highway. A spot speed study is carried out by recording the speeds of a sample of vehicles at a specified location. Speed characteristics identified by such a study would be valid only for the traffic and environmental conditions that exist at the time of the study. To know the impact of Speed Calming in vehicular speeds, speed surveys were undertaken on the selected road segments under this study. Spot speed survey was conducted to collect the traffic speed. Spot speed data was measured by using Laser technology which was found from Addis Ababa City Administration Traffic Management Agency (TMA). Laser technology was chosen for its precision and up-to-date capabilities. It utilizes a velocity speed gun capable of measuring vehicle speeds within a range of 0 to 320 km/h, with a maximum measurement distance of up to 1,200 meters. To ensure accurate readings, it is crucial that the device's radar path closely aligns with the path of the vehicle being measured. The accuracy of the readings is within ±2 km/h when this straight-on path of measurement is approximated (as per the Laser technology manual, 2013).

One speed hump was randomly selected for each road segment, and specific points were chosen for speed data collection at each selected speed hump for every road segment. In the case of the speed humps, three points were selected to conduct a comprehensive speed survey. The first point was located at a distance of 20 meters right before the speed hump (5 meters after the rumble strips). This initial position was crucial for establishing baseline speed data. The second point was precisely at the location of the speed hump, and the third point was situated at a distance of 20 meters right after the speed hump (5 meters before the rumble strips). These intervals, along with the corresponding speeds recorded, would be used in conjunction with available literature to assess the effectiveness of speed calming measures in reducing speed and, consequently, lowering the occurrence of accidents. Speed data was systematically measured for all types of vehicles and accurately recorded in a standard survey form, ensuring a comprehensive data collection process.

The timing of a speed study is contingent on its specific objectives. When the aim is to establish posted speed limits, observe speed trends, or gather fundamental data, it is advisable to conduct the study during periods of free-flowing traffic, often occurring during off-peak hours. In the context of this study, off-peak hours were defined as the morning hours (4:00-6:00 AM) and the afternoon hours (8:00-10:00 AM) local time. The study's duration should be sufficient to record the minimum number of vehicle speeds required for statistical analysis, typically lasting at least one hour and yielding a sample size of at least 30 vehicles, as recommended by Nicholas J. Garber and Lester A. Hoel in 2009. For spot speed studies conducted at specific locations, it is customary to obtain a sample size of at least 50, preferably 100 vehicles, as suggested by Ewing in 1999. Consequently, this study gathered data from 100 vehicles at each designated point for selected speed humps. The speed survey was conducted over a span of seven days, distributed across three weeks: the first week in October 20th, the second week on October 25th, 26th, and 27th, and the final week (third week) on November 1st, 2nd, and 3rd, employing the ERA pavement designs manual Volume I, 2013 Vehicle classification table.

Table 3.2 Vehicle Classification (source: ERA, 2013 Chapter 2 page 3)

Class	Type	Axles	Description
1	Car	2	Passenger cars and taxis
2	Pick-up/4-wheel drive	2	Pick-up, minibus, Land Rovers, Land Cruisers
3	Small bus	2	≤ 27 seats
4	Bus/coach	2	> 27 seats
5	Small truck	2	≤ 3.5 tonnes
6	Medium truck	2 or 3	3.5 – 7.5 tonnes
7	Large truck (Heavy Truck)	2	> 7.5 tonnes
8	Articulated trucks	2 to 6	> 7.5 tonnes and Truck with additional extension

Table 3.3 Spot Speed Study Data Collection Forma

Date:						**Start Time:**			
Data Collector Name:						**End Time:**			
Location:						**Down Time:**			
Speed Limit:						**Weather:**			
Speed	**Car (**2 axle Passenger cars and taxis)	**Pick-up/4-wheel drive** (2 axle Pick-up, minibus, Land Rovers, Land Cruisers)	**Small bus** (2 axle ≤27 seats)	**Bus/coach** (2 axle > 27 seats)	**Small truck** (2 axle ≤3.5 tonnes)	**Medium truck** (2 or 3 axle 3.5 – 7.5 tonnes)	**Large truck** (2axle > 7.5 tonnes)	**Articulated Truck** (3 axle >7.5 tonnes)	**Total**
	No	**No**	**No**	**No**	**No**	**No**	**No**	**No**	

3.4.2. Secondary Data

3.4.2.1. Accident Data

To assess the safety performance of Speed humps with Rumble strips in Addis Ababa, this research incorporated a comprehensive analysis of accident data collected before and after the implementation of these measures on selected road segments within the city. The accident data utilized for this study was sourced from the Addis Ababa Police Commission and various sub-city police departments. Specifically, injury accident data was obtained from Yeka, Lideta, Arada, Gulele, Kolfe Keranio, Nifas Silk Lafto sub-city police departments, while fatality accident data was retrieved from the Addis Ababa Police Commission's accident data records. It's important to note that Ethiopian accident data, like many datasets worldwide, is known to be underreported. Nevertheless, incidents resulting in severe injuries or fatalities are less likely to go unreported, as victims or their families often require a police report for insurance claims.

In classifying the severity of road injuries, a thirty-day period was used as the basis. For instance, injuries were classified as hospitalized if the victim passed away within thirty days of the incident or if they were hospitalized for at least twenty-four hours within thirty days of the collision. The study spanned seven consecutive years, covering the period from 2014 to 2021 (or from 2006 to 2013 E.C), excluding the year of the implementation of speed calming measures. The base period for the analysis was set from July 2017 to July 2018 (or from July 2009 to June 2010 E.C), with a three-year period before implementation (July 2014 to July 2017, or July 2006 to June 2009 E.C) juxtaposed against another three-year period after implementation (July 2018 to July 2021, or July 2010 to June 2013 E.C). The rationale behind this choice of a three-year study was to enhance the reliability of the results. By using this approach, potential one-year anomalies that might distort the findings were mitigated. This allowed for the acquisition of more reliable data and enabled more robust conclusions to be drawn from the study.

3.5. Method of data analysis

3.5.1. Speed survey data analysis

A frequency distribution table serves as a valuable tool for assessing speed percentiles, an essential aspect of understanding speed patterns in traffic data. In this table, the frequency records the number of vehicles observed at different speeds. The cumulative frequency, on the other hand, is determined by progressively summing up the frequencies from lower speeds to higher speeds. The fourth column of this table is dedicated to the cumulative percentage, which signifies the overall percentage of vehicles traveling at speeds up to a specific point. It's important to recognize that the exact 85th percentile speed may not be directly visible in the cumulative percentage column. To derive these precise percentiles, a calculation is performed using the percentages and associated speeds from the distribution table. This computation is more straightforward when the sample size consists of 100 vehicles, as in that scenario, the cumulative frequency and cumulative percentage are equal. The equation for calculating speed percentiles takes into account these considerations, offering a methodical way to determine specific percentiles in the distribution of vehicle speeds Shown below is the equation for calculating speed percentiles:

$$S_D = \frac{P_D - P_{\min}}{P_{\max} - P_{\min}}(S_{\max} - S_{\min}) + S_{\min} ,$$

Where: $\mathbf{S_D}$ = speed at PD, $\mathbf{P_D}$ = percentile desired, $\mathbf{P_{max}}$ = higher cumulative percent, $\mathbf{P_{min}}$ = lower cumulative percent, $\mathbf{S_{max}}$ = higher speed, and $\mathbf{S_{min}}$ = lower speed.

After determining 85th percentile speed for each selected point of all road segments investigation of speed survey data based on the following parameters Speed Variation Based on Distance with respect to speed hump, Vehicle types involved in exceeding posted speed limit, Driver involved in a gender-based speed limit violation, Vehicles exceeding the speed limit by rate and Speed before and after Speed calming implementation to show the figure of speed difference.

3.5.2. Accident data analysis

The research collected and compiled traffic accident data for a three-year period both before and after the implementation of Speed humps with Rumble strips on each of the road segments under investigation. To facilitate meaningful comparisons, this combined accident data was transformed into Equivalent Accident Numbers (EANs) using a point weightage approach. This method, which is inspired by similar work in Malaysia, offers several key advantages. It accounts for all levels of accident severity, including Light (Slight) Injuries, Serious Injuries, and Fatal Accidents, making it a comprehensive tool for evaluating the impact of speed hump implementations. Moreover, the approach provides specific point weights tailored to the context of a developing country like Ethiopia, aligning with the local conditions and circumstances. In this process, each fatal accident was assigned a weightage of six points, serious accidents received four points, and slight injuries were attributed two points. By applying these point weights to the recorded accidents, the data was standardized and structured for a clear and consistent assessment of changes in various parameters, such as Total Accidents, Total Pedestrian Accidents, Pedestrian Accidents Crossing on Roadways, Pedestrian Accidents While Walking Straight, and Accidents Involving Public Transport Vehicles. Microsoft Excel was employed to organize and analyze the before-and-after accident data for each of these variables, with dedicated columns indicating whether there was an increase, decrease, or no change in each variable. This systematic approach facilitated a comprehensive evaluation of the impact of Speed humps with Rumble strips implementations on road safety.

3.5.3. Statistical Analysis Using SPSS

3.5.3.1. T-test for Traffic Speed and Traffic Accident

The data collected on traffic speeds and accidents for the selected road segments was carefully organized and categorized based on relevant criteria. This organized information was then appropriately input into the SPSS program for further analysis. In conducting the statistical analysis, hypothesis testing was employed as the primary method. This approach allowed for a structured examination of the relationships and patterns within the data, enabling the research to draw meaningful conclusions and insights from the information gathered.

Hypotheses test for traffic speed

The null hypothesis

$H0: UD = U1 - U2 = 0$

Alternate hypothesis

$H_A: UD = U1 - U2 \neq 0$

UD = the population's mean of the difference scores between the two measurements (prior location reading and subsequent location reading of traffic speed).

U_1 = mean of prior location traffic speed reading.

U2 = mean of subsequent location traffic speed reading.

Hypotheses test for traffic accident

The null hypothesis

$H0: UD = U1 - U2 = 0$

Alternate hypothesis

$H_A: UD = U1 - U2 \neq 0$

UD = the population's mean of the difference scores between the two measurements (both before and after speed humps with rumble strips were installed).

U1 = mean before speed humps with rumble strips were installed.

U2 = mean after speed humps with rumble strips were installed.

This was done using SPSS software, for the t-test, the value of Alpha was selected at 0.05. While larger Alpha values are commonly used (i.e. typically 0.05, to ensure 95% level of confidence or 0.1, to ensure a 90% level of confidence), a higher level of confidence was selected to guarantee the confidence of the results considering the small sample sizes in this research (13 samples). The P-value was also determined for each of the areas under study. If the p-value was less than the selected Alpha value of 0.05 reject the null hypothesis and then the relationship was determined to be significant and if the p-value was greater than the selected Alpha value of 0.05 then the relationship was determined to be insignificant.

3.5.3.2. Regression Analysis and Model development

The relation between 85th Percentile Crossing speed and speed hump density developed using the linear regression method by choice model parameters.

CHAPTER FOUR

ANALYSIS AND RESULTS

The data analysis and results in this research encompass three primary components: spot speed data analysis and results, accident data analysis and results, and regression analysis and results. Each of these components is integral to the overall assessment of the effectiveness of speed humps with rumble strips in enhancing road safety.

4.1. Investigation of Speed Survey Data

In order to assess the effectiveness of speed humps in reducing travel speeds, a comprehensive speed survey was conducted on all the roads included in this research. This survey played a critical role in gathering valuable data and insights regarding the impact of speed humps on vehicular speeds. The information collected through this survey was instrumental in evaluating the extent to which speed humps influenced driver behavior and road safety, providing valuable insights for the research's conclusions and recommendations.

Sample Calculation Speed (20m before speed hump) @Mendida intersection to Torhayloch Road segment

The 85th percentile of speed (PD = 85%) falls between 44 km/hr and 45 km/hr (see Table 4- below), so Smax = 45 km/hr and Smin = 44 km/hr. The higher cumulative percent (Pmax) is 87%, and the lower cumulative percent (Pmin) is 82%. Therefore, to find SD at PD = 85%:

$$SD = \frac{PD - Pmin}{Pmax - Pmin} * (Smax - Smin) + Smin$$

$$SD = \frac{85\% - 82\%}{87\% - 82\%} * (45\ \text{km/hr} - 44\ \text{km/hr}) + 44\ \text{km/hr}$$

$$SD = \frac{3\%}{5\%} * (1\ \text{km/hr}) + 44\ \text{km/hr}$$

$$\boldsymbol{SD = 44.6\ \text{km/hr} \approx 45\text{km/hr}}$$

Table 4-1. Sample Spot Speed Calculation.

Analysis of Spot speed (20m before speed hump) @Mendida intersection to Tor hayloch Road segment				
Speed(km/hr)	**Frequency of Vehicles**	**Cumulative Frequency**	**Cumulative Percent**	**Speed Percentile**
23	1	1	1%	
30	1	2	2%	
31	3	5	5%	
32	2	7	7%	
33	6	13	13%	
34	3	16	16%	
35	2	18	18%	
36	2	20	20%	
37	6	26	26%	
38	11	37	37%	
39	10	47	47%	
40	14	61	61%	
41	5	66	66%	
42	6	72	72%	
43	7	79	79%	
44	3	82	82%	**85th**
45	5	87	87%	
46	1	88	88%	
47	3	91	91%	
48	2	93	93%	
49	2	95	95%	
51	1	96	96%	
52	2	98	98%	
55	1	99	99%	
57	1	100	100%	

Table 4-2. Summarized 85th Percentile Spot Speed Result.

Road segments	After 20m of speed hump	At the speed hump	Before 20m of speed hump
Bethel RA-----Keranyo RA	30	23	23
Anfo RA-----Keranyo RA	24	18	20
Mendida intersection---Tor hayloch	45	39	45
Lideta interchange---AU Junction (LidetaTsebel)	33	23	32
Mekanisa Abo RA---Mekanisa bridge	33	21	31
BisrateGebriel-----Mekanisa Abo RA	34	29	39
Lideta Condominium-------Lideta interchange	31	28	26
Semen hotel signalized intersection--Afinchober	27	17	27
Balderas condominium----Aware RA	31	17	27
Parlama signalized intersection-----Aware RA	29	18	28
KokebeTsibah secondary School----Kebena RA	31	20	35
Minilik II hospital-------Kebena RA	33	21	30
6 kilo RA--Afinchober	33	21	36

4.1.1. Speed Variation Based on Distance with respect to speed hump

As it is presented on the figure below, Figure 4-2, from the survey there was a consistent difference between Point 2(at the speed hump) and the two other Points 1 and 3, the points closest to the two speed humps. The 85th percentile speed at Point 2 was lower than for both point 1 and 3, this consistent difference was for both road segments traffic. From results, vehicles accelerate before speed hump and slow down immediately at the speed hump. Immediately after driving off, vehicles then start to accelerate.

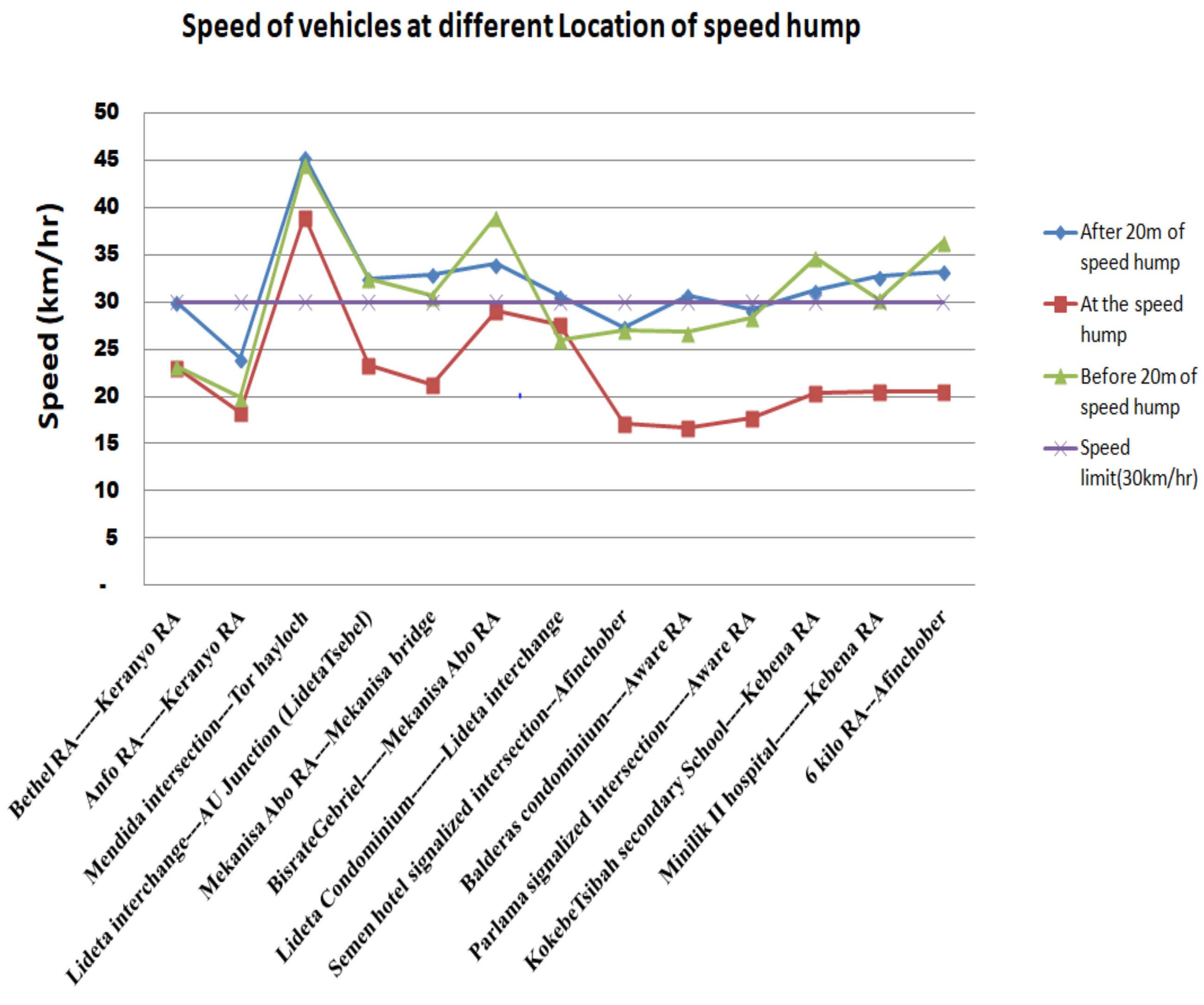

Figure 4 - 1: 85th Percentile speed of selected road segments at different location

4.1.2. Vehicle types involved in exceeding posted speed limit

As can be observed from Figure 4-3 below, the distribution of vehicle types involved in exceeding posted speed limit at 20 meter before the Speed humps location Car (Passenger cars and taxis) , Pick-up/4-WD (Pick-up, minibus, Land Rovers, Land Cruisers) and Large truck (Large 2-axled truck >7.5 tonnes) counted for the largest proportion of vehicle types in the overall traffic volume with respect to total sampled road segments.their value vary from 10% to 92%, 8% to 43% and 0% to 55% respectively.when we can see the the road segment which can counts lowest and highest proportion value for car Mekanisa Abo RA to Mekanisa bridge and Parlama signalized intersection to Aware RA, Pick-up/4-WD Parlama signalized intersection to Aware RA and Balderas condominium to Aware RA for Large truck Balderas condominium to Aware RA, Semen hotel signalized intersection to Afinchober, Minilik II hospital to Kebena RA, Bethel RA to Keranyo RA, Lideta Condominium to Lideta interchange, Parlama signalized intersection to Aware RA and Mekanisa Abo RA to Mekanisa bridge from lowest to highest value respectively.

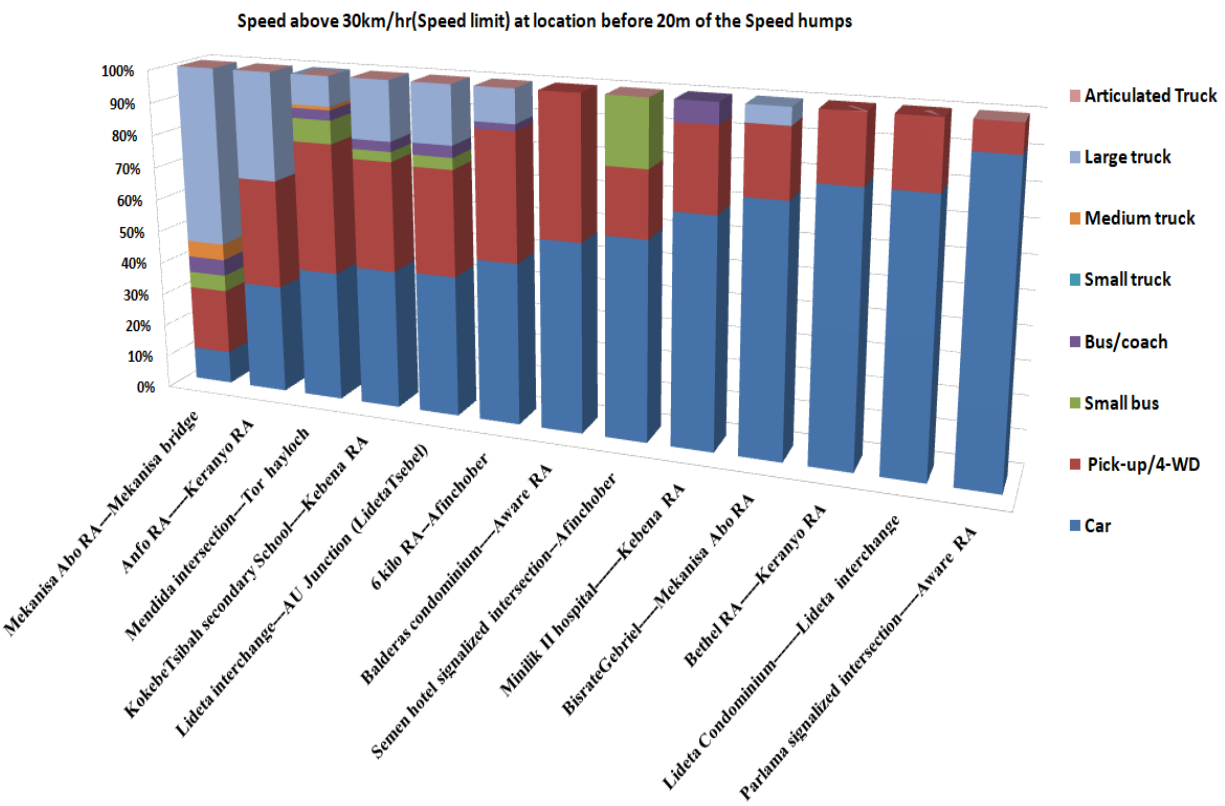

Figure 4 - 2: 85th Percentile speed above speed limit (30km/hr) by vehicle type at location 20m before the speed humps

As it is shown on the Figure 4-4 below, the distribution of vehicle types involved in exceeding posted speed limit at the Speed humps location. As an analysis, result confirms that number of vehicles exceeding posted speed limit caused by Car (Passenger cars and taxis) and Pick-up/4-WD (Pick-up, minibus, Land Rovers, Land Cruisers), Large truck (Large 2-axled truck >7.5 tonnes), Articulated Truck (>7.5 tonnes and Truck with additional extension), Medium truck, Bus/coach (> 27 seats) and Small bus (≤ 27 seats) involved on the selected road segment with the percentage of 38%, 38%, 23%, 8%, 8%, 8% and 8% respectively out of total sampled road segment with the proportion of 33% to 100%, 17% to 100%,4% to 50%,only 17%, only 3%, only 3% and only 1% respectively.

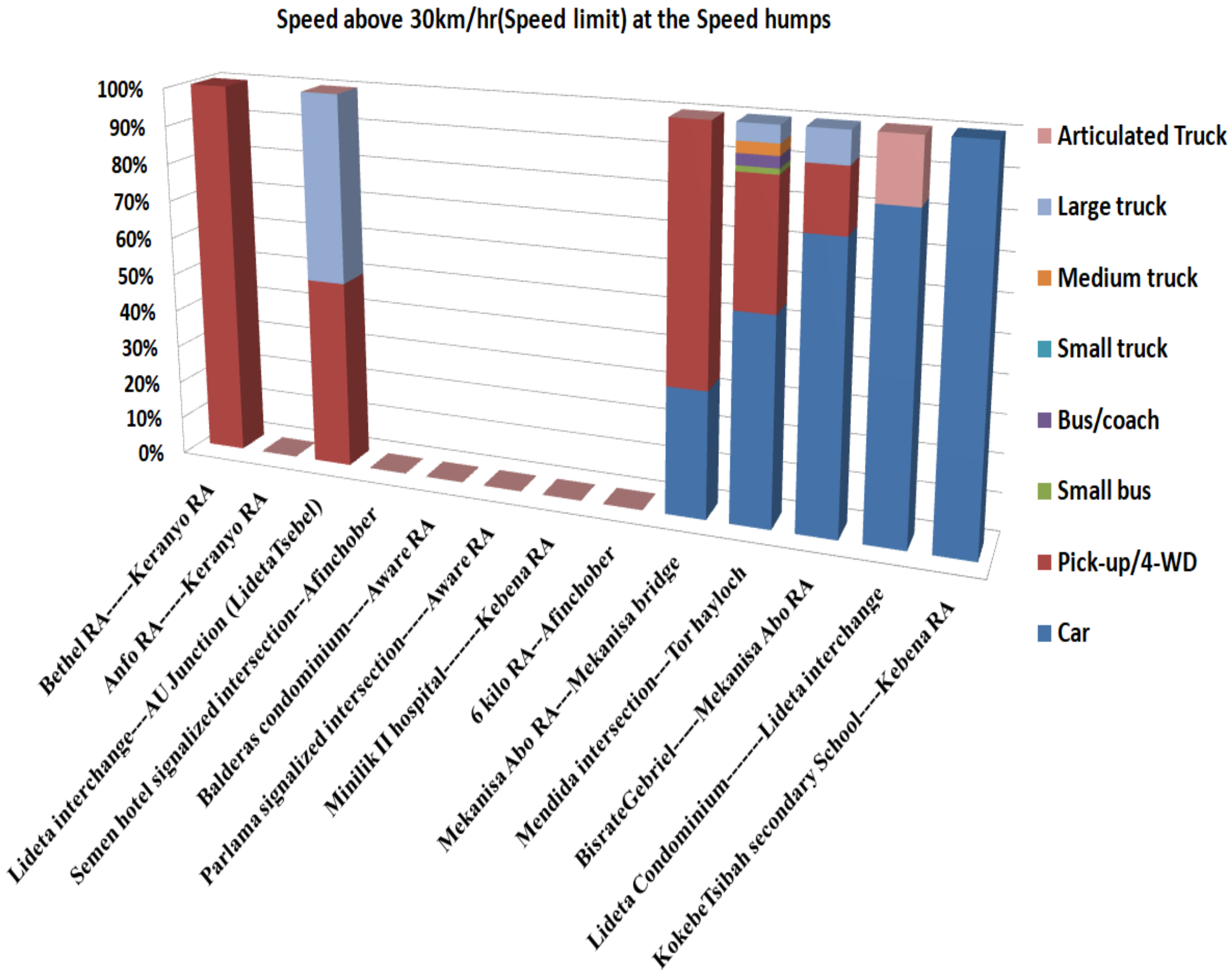

Figure 4 - 3: 85th Percentile speed above speed limit (30km/hr) by vehicle type at location of the speed humps

As it is shown on the Figure 4-5 below,the distribution of vehicle types involved in exceeding posted speed limit at 20 meter after the Speed humps location. As an analysis, result confirms that number of vehicles exceeding posted speed limit caused by Car (Passenger cars and taxis) and Pick-up/4-WD (Pick-up, minibus, Land Rovers, Land Cruisers), Large truck (Large 2-axled truck >7.5 tonnes), Bus/coach (> 27 seats), Medium truck and Small bus (≤ 27 seats) involved on the selected road segment with the percentage of 92%, 92%, 77%, 38%, 15% and 15% respectively out of total sampled road segment with the lowest and highest proportion of 42% to 88%, 13% to 42%,1% to 100%,2% to 12%,3% to 3% and 1% to 2%,respectively.but when we can see the the road segment which can counts lowest and highest proportion value for car Mekanisa Abo RA to Mekanisa bridge and Parlama signalized intersection to Aware RA, Pick-up/4-WD Parlama signalized intersection to Mekanisa Abo RA to Mekanisa bridge for Large truck Mendida intersection to Tor hayloch and Anfo RA to Keranyo RA,For Bus/coach (> 27 seats) 6 kilo RA to Afinchober and Mekanisa Abo RA to Mekanisa bridge,For Medium truck Lideta interchange to AU Junction (LidetaTsebel) and Mendida intersection to Tor hayloch equally and for Small bus (≤ 27 seats) Mendida intersection to Tor hayloch and 6 kilo RA to Afinchober from lowest to highest value respectively.

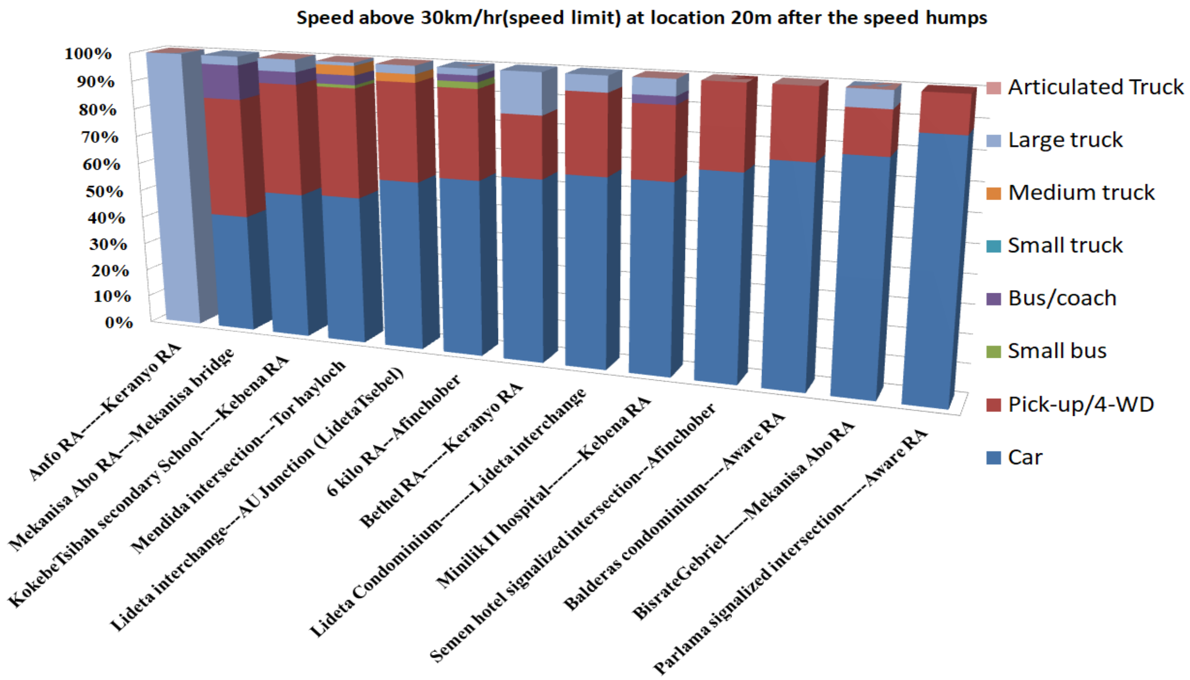

Figure 4 - 4: 85th Percentile speed above speed limit (30km/hr) by vehicle type at location 20m after the speed humps

4.1.3. Driver involved in exceeding the speed limit by gender

As it is shown on the Figure 4-6 below, the percentage of vehicles observed in exceeding posted speed limit by gender at 20 meter before the Speed humps location, As an analysis, result confirms that exceeding posted speed limit caused by male is involved in all selected road segments and its value vary from 86% to 100% but when we can see exceeding posted speed limit by female it is involved only in 46%(6 out of 13) of road segment and its value varying from 0% to 14% from smallest to largest respectively. This implies that exceeding speed limit is highly associated with male driver than female driver.

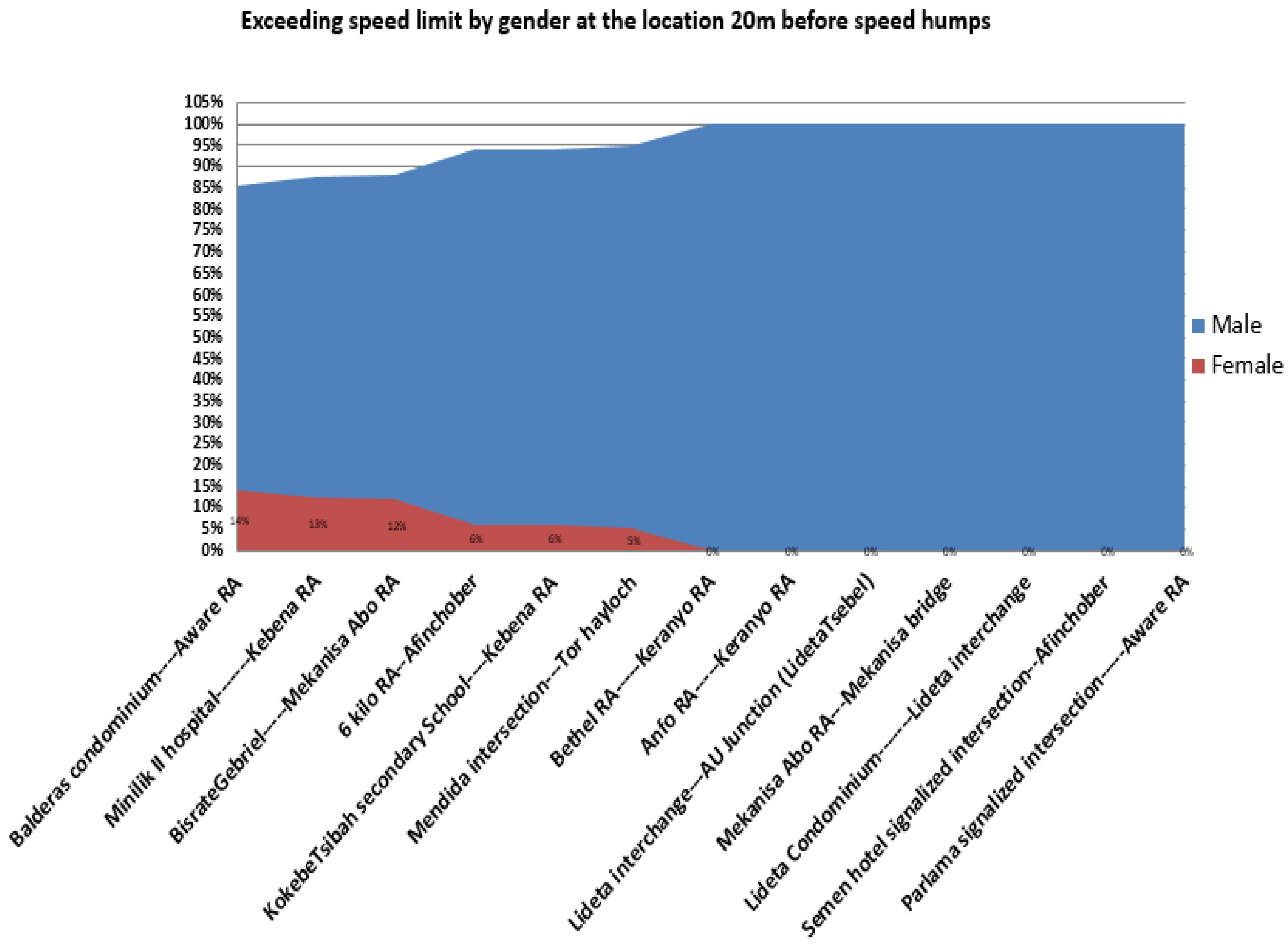

Figure 4 - 5: 85th Percentile speed above speed limit (30km/hr) by gender at location 20m before the speed humps

As it is shown on the Figure 4-7 below, the percentage of vehicles observed in exceeding posted speed limit by gender at the Speed humps location, As an analysis, result confirms that exceeding posted speed limit caused by male is involved in 54% (7 out of 13) of selected road segments and its value vary from 83% to 100% but when we can see exceeding posted speed limit by female it is involved only in 23%(3 out of 13) of road segment and its value varying from 0% to 17% from smallest to largest respectively. This implies that exceeding speed limit is highly associated with male driver than female driver.

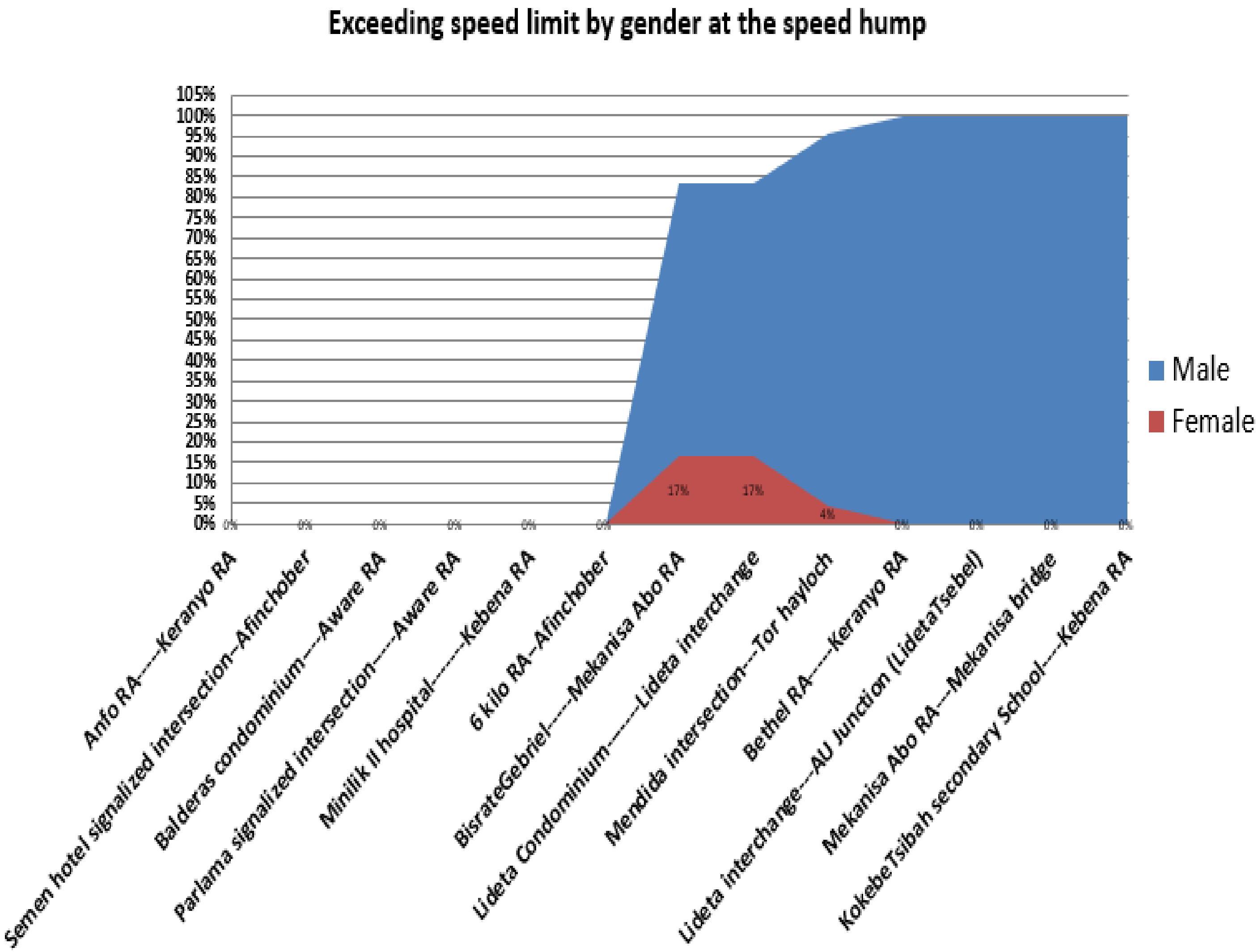

Figure 4 - 6: 85th Percentile speed above speed limit (30km/hr) by gender at location of the speed humps

As it is shown on the Figure 4-8 below, the percentage of vehicles observed in exceeding posted speed limit by gender at 20 meter after the Speed humps location. As an analysis, result confirms that exceeding posted speed limit caused by male is involved in all selected road segments and its value vary from 85% to 100% but when we can see exceeding posted speed limit by female it is involved only in 46%(6 out of 13) of road segment and its value varying from 0% to 15% from smallest to largest respectively. This implies that exceeding speed limit is highly associated with male driver than female driver.

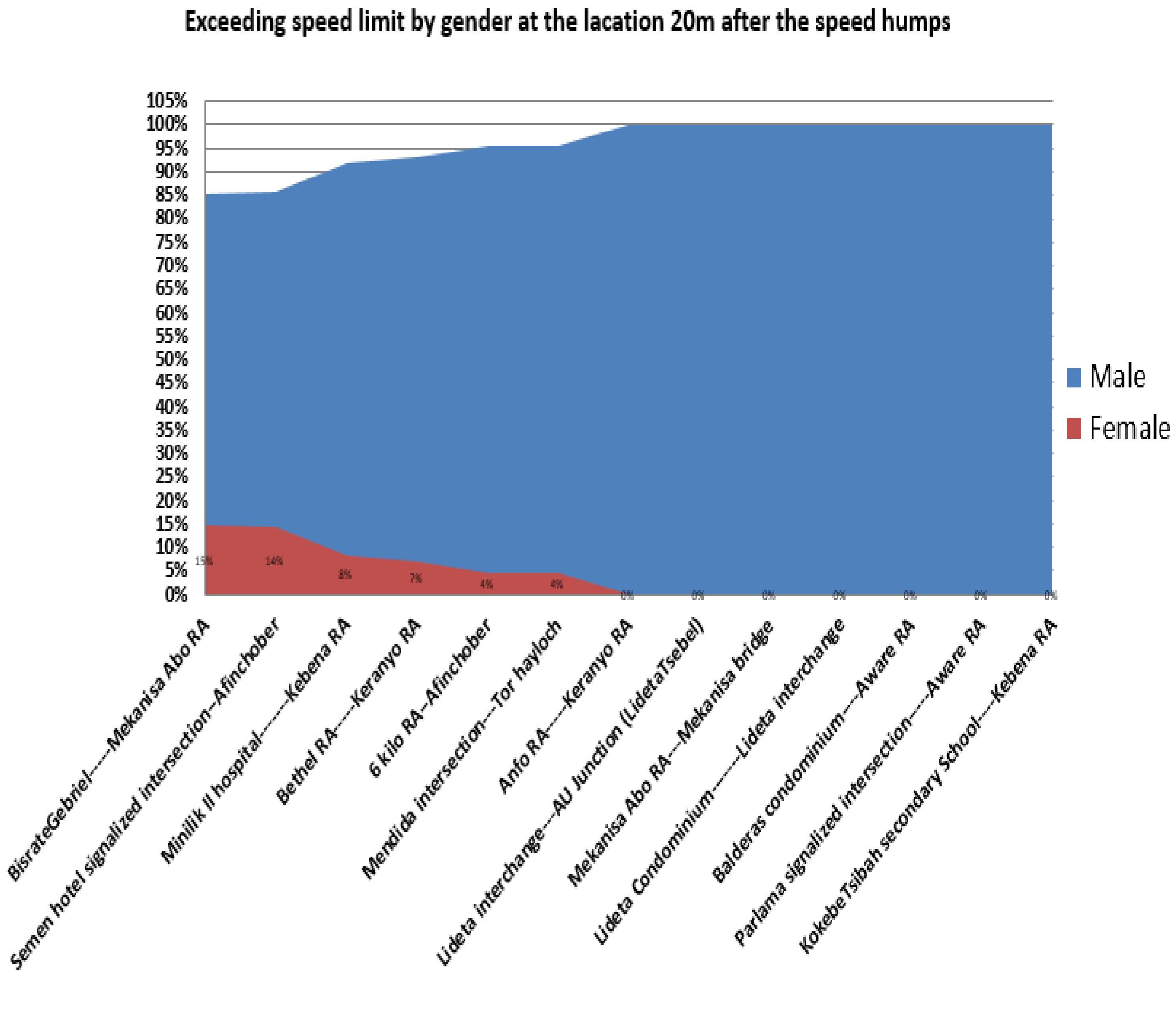

Figure 4 - 7: 85th Percentile speed above speed limit (30km/hr) by gender at location 20m after the speed humps

4.1.4. Vehicles exceeding the speed limit by rate

As it is shown on the Figure 4-9 below, the percentage of vehicles observed in exceeding posted speed limit by different rate at 20 meter before the Speed humps location, As an analysis, result confirms that exceeding posted speed limit caused by rate of more than 5 km/h, more than 10 km/h, more than 15 km/h and more than 20 km/h is 92 %(12 out of 13), 31 %(4 out of 13), 23 %(3 out of 13) and 23 %(3 out of 13) respectively for sampled road segments.

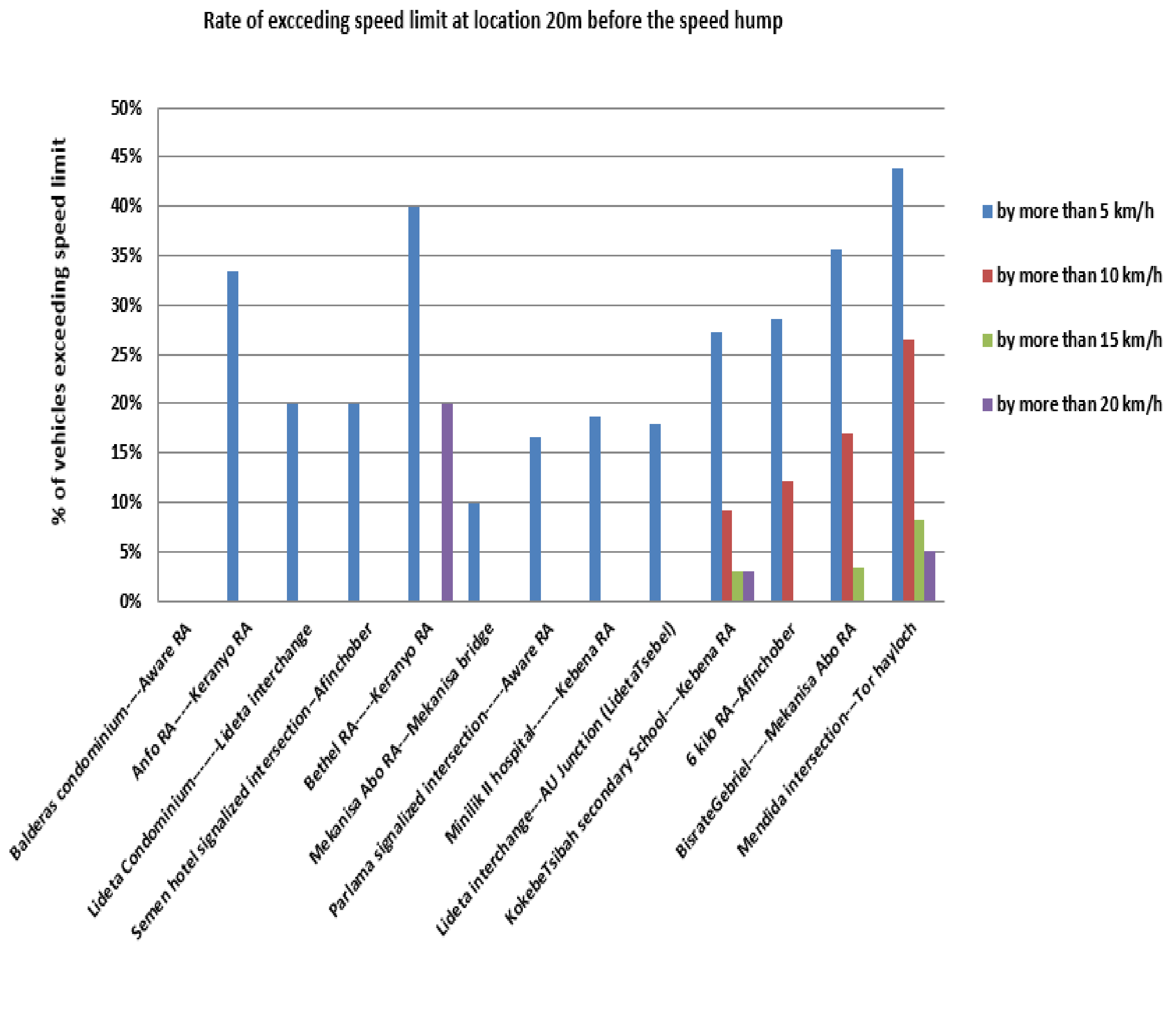

Figure 4 - 8: 85th Percentile speed above speed limit (30km/hr) by rate at location 20m before the speed humps

As it is shown on the Figure 4-10 below, the percentage of vehicles observed in exceeding posted speed limit by different rate at the Speed humps location. As an analysis, result confirms that exceeding posted speed limit caused by rate of more than 5 km/h, more than 10 km/h, more than 15 km/h and more than 20 km/h is 31% (4 out of 13), 8% (1 out of 13), 15% (2 out of 13) and 8% (1 out of 13) respectively for sampled road segments.

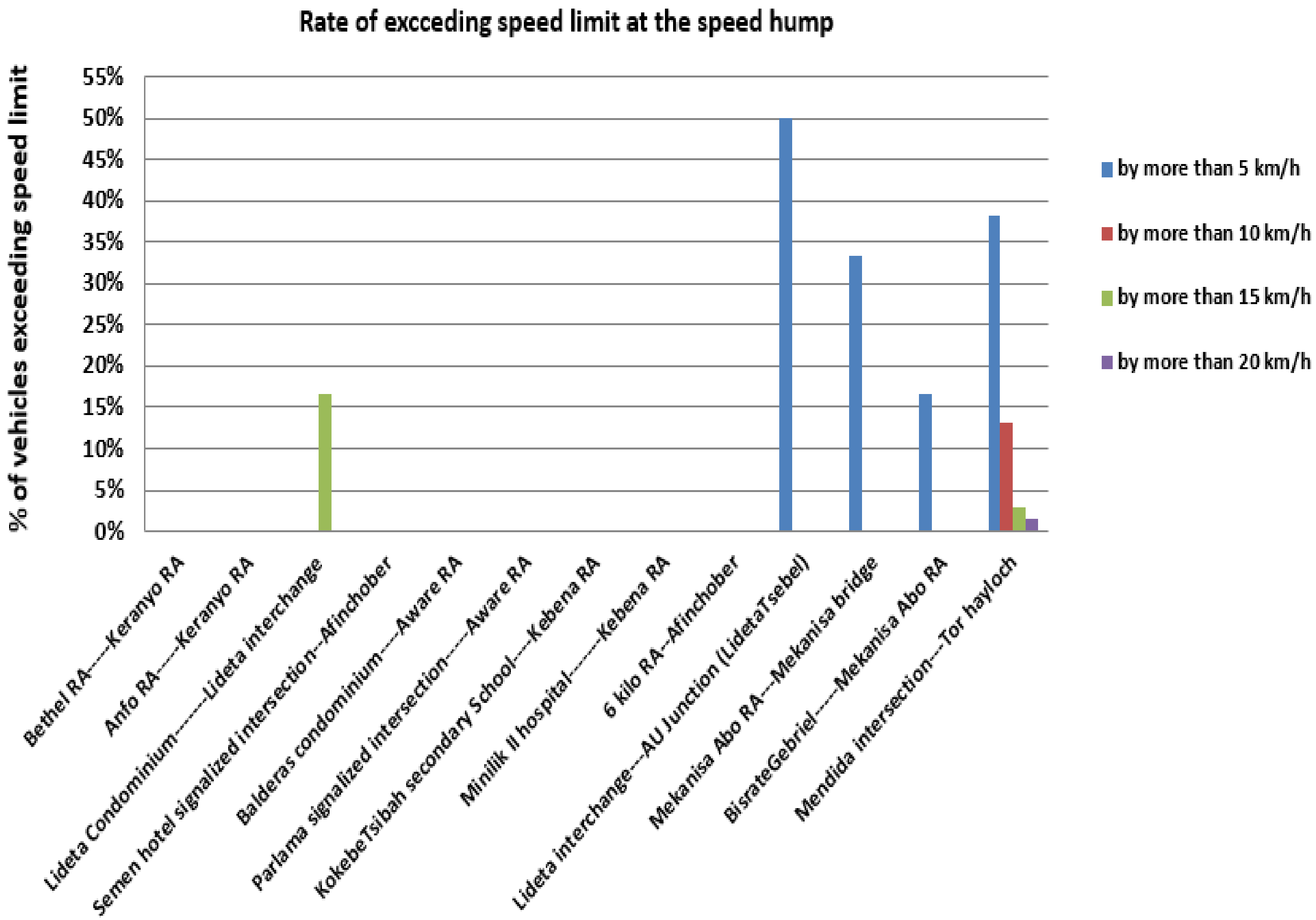

Figure 4 - 9: 85th Percentile speed above speed limit (30km/hr) by rate at location of the speed humps

As it is shown on the Figure 4-11 below, the percentage of vehicles observed in exceeding posted speed limit by different rate at 20 meter after the Speed humps location. As an analysis, result confirms that exceeding posted speed limit caused by rate of more than 5 km/h, more than 10 km/h, more than 15 km/h and more than 20 km/h is 77% (10 out of 13), 54% (7 out of 13), 15%(2 out of 13) and 8% (1 out of 13) respectively for sampled road segments.

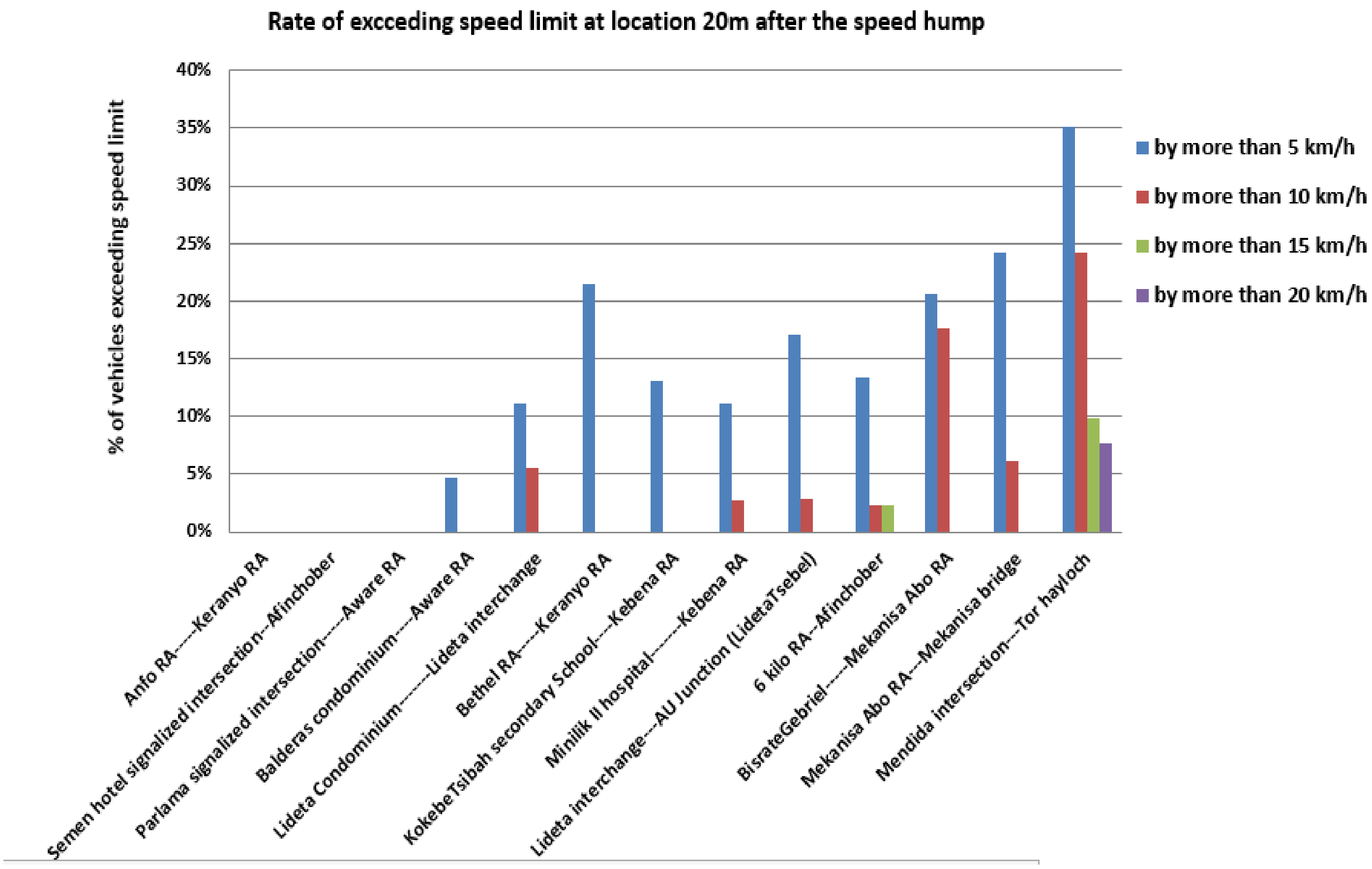

Figure 4 - 10: 85th Percentile speed above speed limit (30km/hr) by rate at location 20m after the speed humps

4.1.5. Speed before and after Speed calming implementation

This implies that Collecting speed data on subject road segments both before changes are made as well as after speed calming (speed humps with rumble strips) designs are implemented. To determine the effectiveness of implemented speed calming (speed humps with rumble strips) measure with respect to speed reduction. This study also tries to examine implemented speed humps with rumble strips effectiveness with respect to travel speed reduction for this purpose we can select road segments based on available before speed data. Due to lack of before data only two road segments (Lideta interchange to AU Junction (LidetaTsebel) and Lideta Condominium to Lideta interchange) are selected for this case.

As it is shown on the Figure 4-11 below, Installation of the speed humps with rumble strips reduced the average operating speeds by 41% (After 20m of speed hump and Before 20m of speed hump), 47% (Average speed after speed humps with rumble strips implementation), and 58% (At the speed hump) for Lideta interchange---AU Junction (LidetaTsebel) and For Lideta Condominium--Lideta interchange, the average operating speeds was reduced by 38% (After 20m of speed hump), 47% (Average speed after speed humps with rumble strips implementation), 44% (At the speed hump) and 48% (Before 20m of speed hump).

In summary, the results of analyzing the average operating speeds indicate a reduction in vehicle speeds from before to after periods of between 41% to 58% for Lideta interchange---AU Junction (LidetaTsebel) and 38% to 48 % Smallest to largest, respectively.

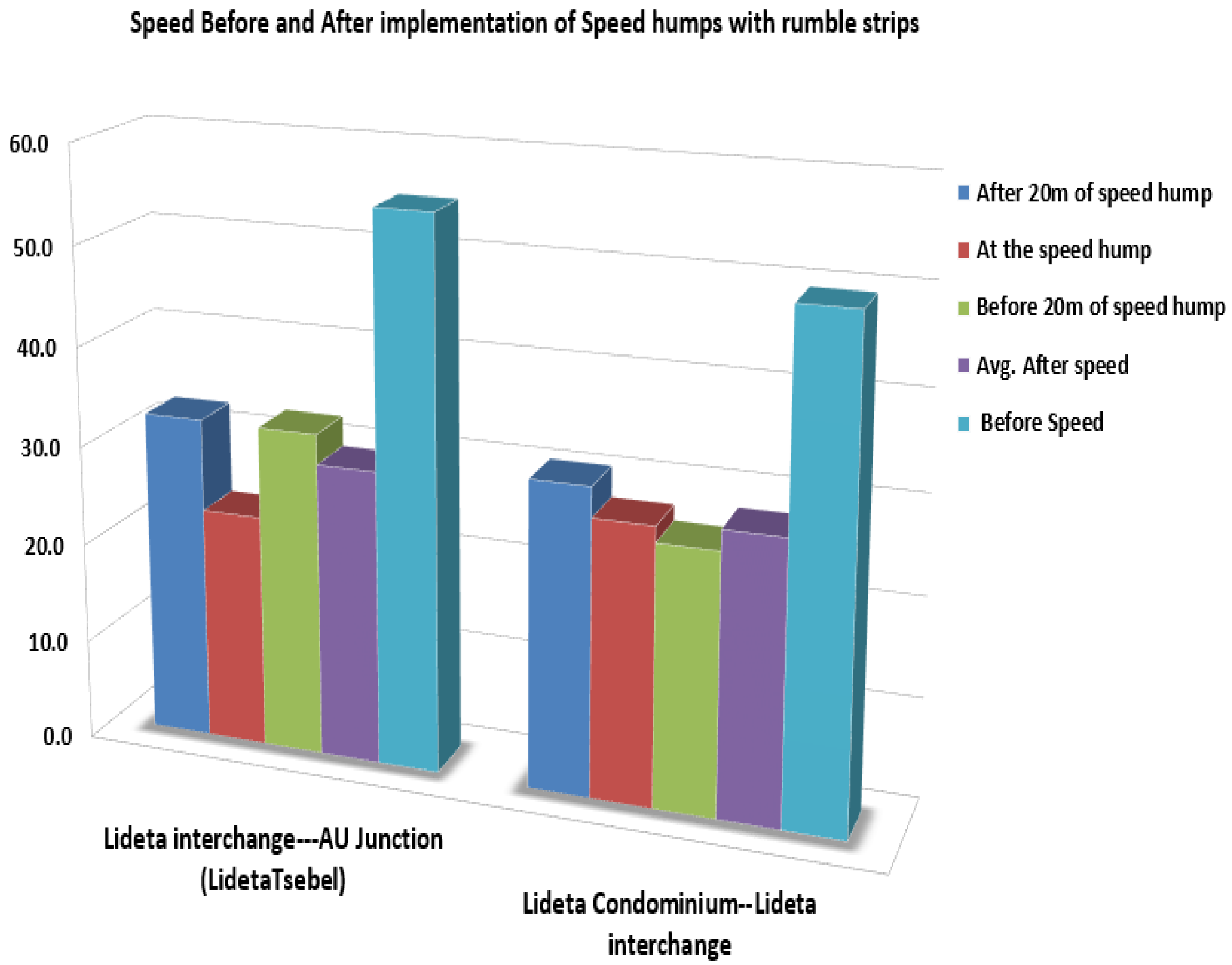

Figure 4-11. 85th Percentile speed before and after implementation of speed humps with rumble strips

4.2. Investigation of Traffic Accident Data

4.2.1. Change in Total Accidents

The number of accidents before and after the implementation of speed humps with rumble strips was quantified using the Equivalent Accident Number (EAN). The EAN assigns weighted values to accidents based on their severity, with higher scores reflecting more severe incidents. In this scoring system, fatal accidents received the highest score, with six points assigned to death accidents. Accidents resulting in severe injuries were awarded four points, while those leading to light injuries received two points. This approach allowed for a comprehensive assessment of the impact of speed humps with rumble strips on road safety, accounting for the severity of accidents in the evaluation process.

Table 4-3. Comparison of total accidents before and after implementation of speed humps with rumble strips

Road Name	EANs Before	EANs After	Change
Bethel RA-----Keranyo RA	94	74	-20
Anfo RA-----Keranyo RA	120	96	-24
Mendida intersection---Tor hayloch	126	66	-60
Lideta interchange---AU Junction (LidetaTsebel)	170	110	-60
Mekanisa Abo RA---Mekanisa bridge	148	70	-78
BisrateGebriel-----Mekanisa Abo RA	70	58	-12
Lideta Condominium-----Lideta interchange	86	96	10
Semen hotel signalized intersection--Afinchober	72	52	-20
Balderas condominium----Aware RA	24	30	6
Parlama signalized intersection-----Aware RA	114	82	-32
KokebeTsibah secondary School----Kebena RA	48	22	-26
Minilik II hospital-------Kebena RA	78	52	-26
6 kilo RA--Afinchober	48	16	-32

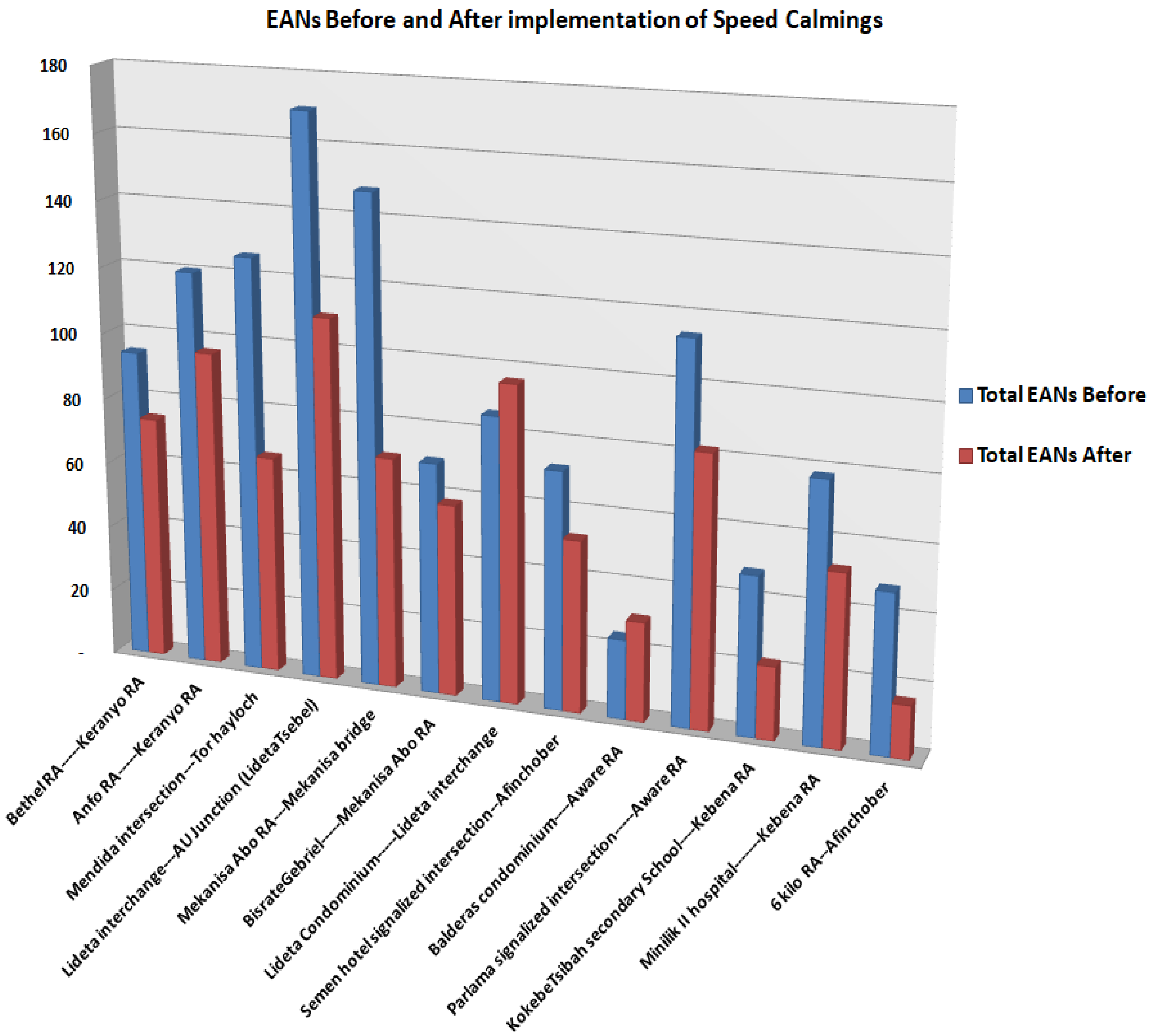

Figure 4 - 12: Total accidents before and after implementation of speed humps with rumble strips

In the three years preceding the implementation of speed humps with rumble strips, there were a total of 1,198 EANs (Equivalent Accident Number) recorded on the road segments s selected for this study. However, following the implementation of these speed humps with rumble strips, the total number of accidents significantly reduced to 824 over the course of the subsequent three years. This reduction represents a substantial 31.22% decline in road accidents.

Furthermore, the data revealed that the majority of the roads under study, specifically 11 out of the 13 roads (85%), experienced a decline in the number of accidents. This aligns with existing literature, affirming the efficacy of speed calming measures in reducing accidents and improving road safety. Notably, only two roads stood as outliers, showing an increase in the total number of accidents. The extent of change varied from one road to another.

The most significant change, in terms of EANs, was observed on the Mekanisa Abo RA to Mekanisa Bridge Road segment, which had 148 EANs before the implementation of speed humps with rumble strips and saw a considerable reduction to 70 EANs after the implementation. These findings emphasize the overall success of speed humps with rumble strips in reducing accidents.

4.2.2. Change in Total Pedestrian Accidents

Another crucial objective of this research was to assess the effectiveness of speed humps with rumble strips in enhancing pedestrian safety within the city of Addis Ababa. This assessment aligned with the overarching goal of the Addis Ababa Road Safety Strategy for 2017-2030, which focuses on reducing road traffic deaths and injuries while striving to make Addis Ababa the most livable city. By examining the impact of speed humps with rumble strips on pedestrian safety, this research contributed to the broader mission of creating a safer, more pedestrian-friendly urban environment and driving forward the city's commitment to road safety and livability.

Table 4-4. Comparison of pedestrian accidents before and after implementation speed humps with rumble strips

Road Name	Pedestrian EANs Before	Pedestrian EANs After	Change
Bethel RA-----Keranyo RA	34	36	2
Anfo RA-----Keranyo RA	74	72	-2
Mendida intersection---Tor hayloch	30	36	6
Lideta interchange---AU Junction (LidetaTsebel)	126	56	-70
Mekanisa Abo RA---Mekanisa bridge	58	54	-4
BisrateGebriel-----Mekanisa Abo RA	56	32	-24
Lideta Condominium-----Lideta interchange	76	76	0
Semen hotel signalized intersection--Afinchober	60	52	-8

Balderas condominium----Aware RA	18	24	6
Parlama signalized intersection-----Aware RA	72	44	-28
KokebeTsibah secondary School----Kebena RA	26	8	-18
Minilik II hospital-------Kebena RA	34	32	-2
6 kilo RA--Afinchober	48	16	-32
Total pedestrians involved before implementation		**712**	
Total pedestrians involved after implementation		**538**	

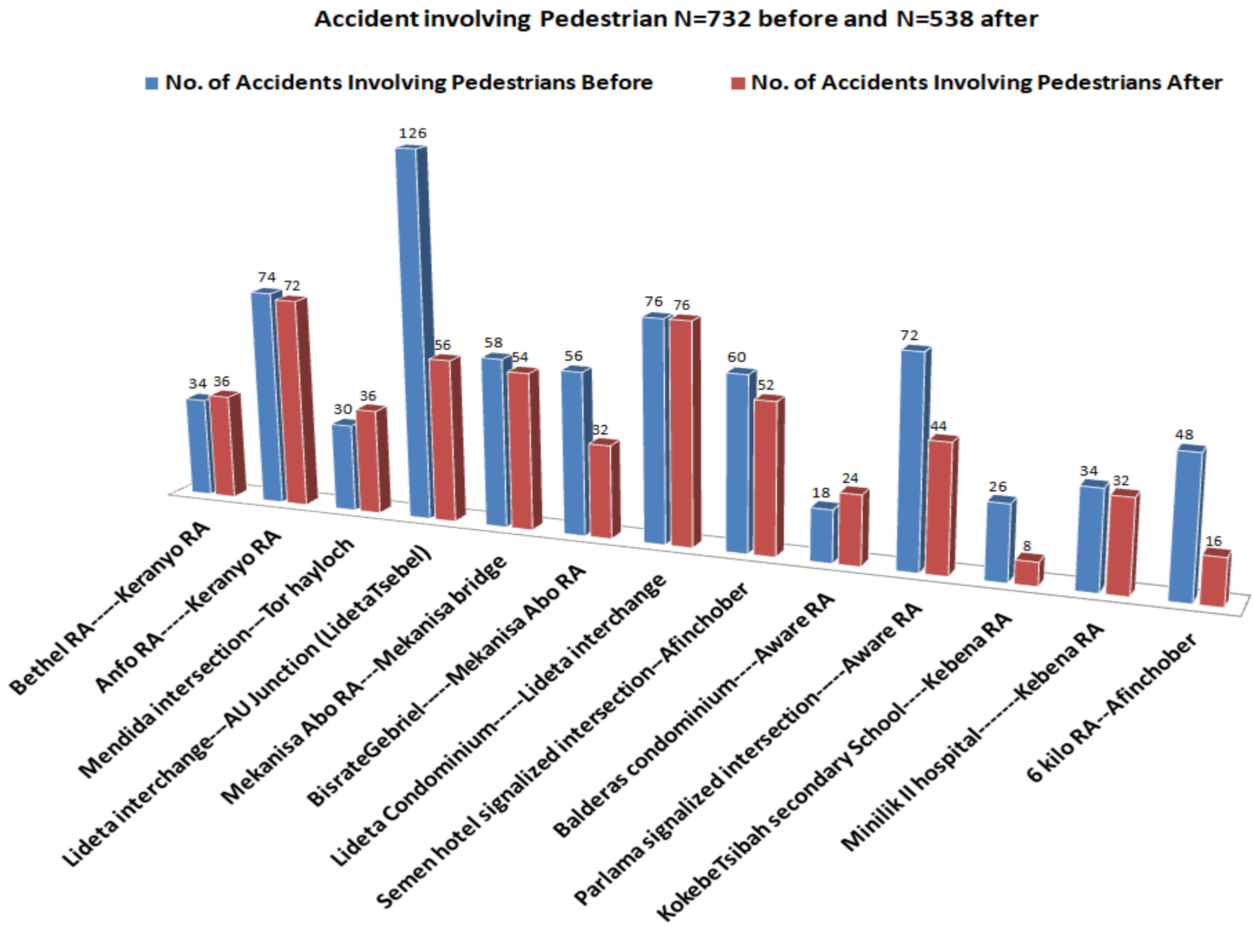

Figure 4 - 13: Total pedestrian accidents before and after implementation speed humps with rumble strips

In the three years leading up to the implementation of speed humps with rumble strips, there were a total of 712 pedestrians involved in road crashes on the roads under study. However, following the installation of speed humps with rumble strips, there was a notable reduction in the number of pedestrians involved, which decreased from 712 to 538, indicating a significant 24% reduction in pedestrian-related accidents.

The most substantial change was particularly observed on the Lideta interchange to AU Junction (LidetaTsebel) Road segments. Here, there were 126 pedestrians who fell victim to road crashes before the implementation of speed humps with rumble strips. After the measures were put in place, this number saw a considerable reduction, declining to just 56 incidents, underscoring the substantial improvement in pedestrian safety.

It's important to note that, in contrast, three out of the 13 road segments, namely the Mendida intersection to Tor hayloch, Balderas condominium to Aware RA, and Bethel RA to Keranyo RA Roads, experienced an increase in the number of pedestrian incidents after the installation of speed humps with rumble strips. However, road segments where there were no incidents involving pedestrians both before and after the implementation of speed humps with rumble strips were not depicted in Figure 4. 12 These findings emphasize the overall positive impact of speed humps with rumble strips in reducing pedestrian-related accidents across the majority of the studied road segments while highlighting the need for targeted interventions in specific areas.

4.2.3. Change in Pedestrian Accidents Crossing on Roadway

The study went a step further by categorizing pedestrian accidents based on the main activity, with a specific focus on pedestrians who were involved in accidents while crossing on the roadway. This detailed analysis aimed to determine if there was a noticeable change in the number of pedestrians struck by vehicles after the implementation of speed humps with rumble strips. Furthermore, the study sought to assess the extent and margin of statistical significance, if any, in these changes.

This information holds significant importance as it provides critical insights into the impact of speed humps with rumble strips on pedestrian safety, particularly during roadway crossing activities. Understanding these changes and their statistical significance is crucial for enhancing road safety strategies and ensuring that pedestrians can traverse roadways with a keen sense of safety and security, aligning with the broader objective of creating a safer and more pedestrian-friendly urban environment.

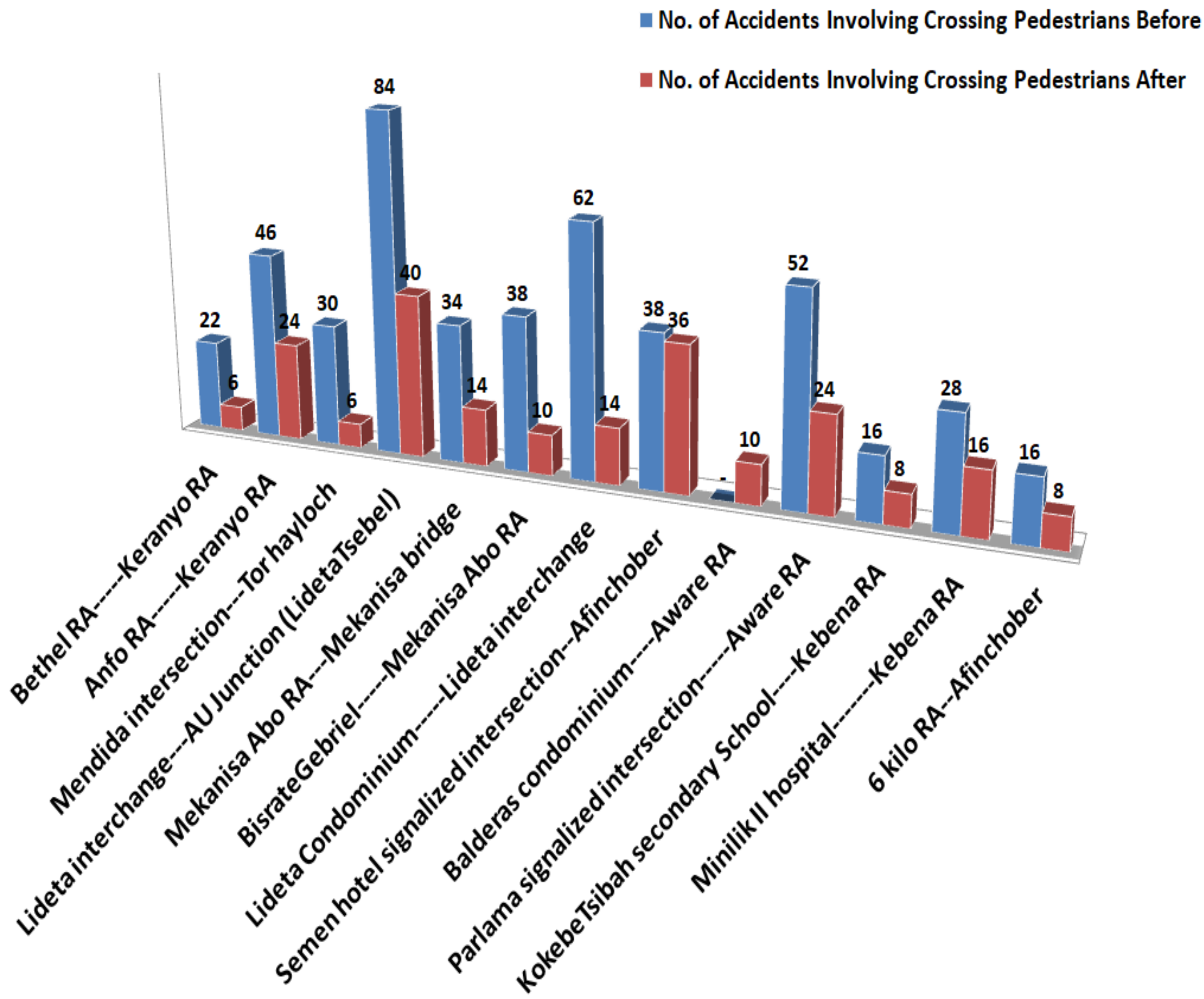

Figure 4 - 14: Pedestrian accidents crossing on Roadway before and after implementation speed humps with rumble strips

In the three years preceding the implementation of speed humps with rumble strips, there were a total of 466 accidents involving pedestrians engaged in crossing activities on the road segments under study. However, following the installation of speed humps with rumble strips, there was a remarkable reduction in the number of pedestrians involved in crossing activities. The figure decreased from 466 to 216, reflecting a substantial 54% reduction in such incidents.

The most significant change was notably observed on the Lideta Condominium to Lideta interchange Road segment, where the number of pedestrians involved in road crashes while crossing activities prior to the implementation of speed humps with rumble strips stood at 62. After the measures were put in place, this number saw a drastic reduction, falling to just 14 incidents. This underscores the considerable impact of speed humps with rumble strips on enhancing pedestrian safety during crossing activities.

However, it's important to note that only one out of the 13 road segments, specifically the Balderas condominium to Aware RA Road segment, experienced an increase in the number of pedestrian incidents involved in crossing activities after the installation of speed humps with rumble strips. These findings emphasize the overall effectiveness of these measures in reducing accidents involving pedestrians during crossing activities and contribute to the overarching goal of improving road safety for pedestrians.

4.2.4. Change in Pedestrian Accidents Walking Straight

The study took a deeper dive into pedestrian accidents by categorizing them based on the activity of the pedestrians, specifically focusing on those who were involved in accidents while walking straight. This granular analysis aimed to determine if there was a notable change in the number of pedestrians struck by vehicles after the implementation of speed calming measures. Furthermore, it sought to assess the extent and margin of statistical significance, if any.

This information holds significant relevance, particularly in the context of the Addis Ababa Road Safety Strategy, which places a paramount emphasis on prioritizing pedestrian safety. With the overarching goal of making Addis Ababa a more livable city, it is essential that pedestrians feel a strong sense of safety when using the road network, especially on residential roads. By scrutinizing pedestrian accidents and their causes, the study contributes to the city's efforts to enhance pedestrian safety, thereby promoting a more pedestrian-friendly and safer urban environment.

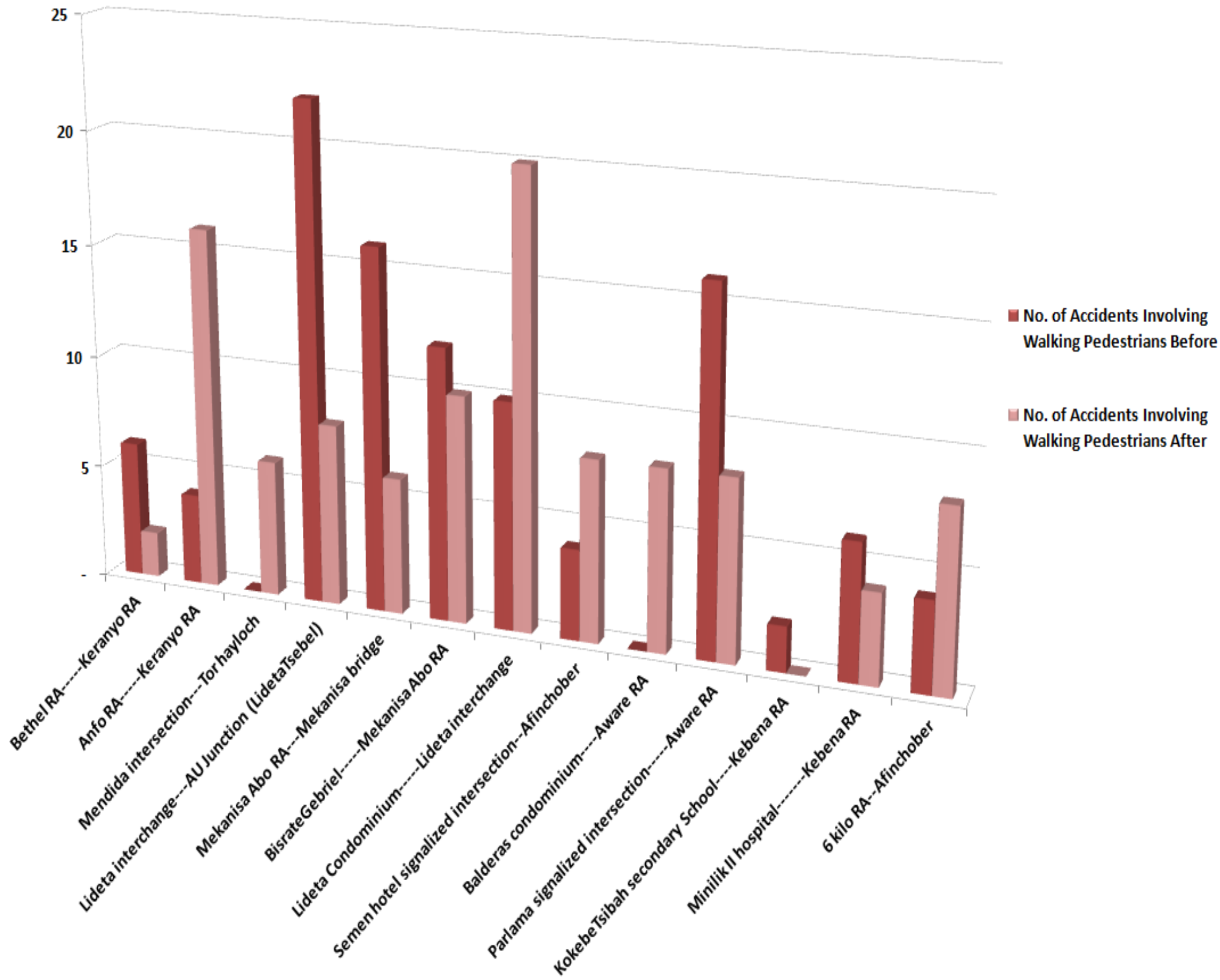

Figure 4 - 15: Pedestrian accidents walking straight before and after implementation speed humps with rumble strips

Prior to the implementation of speed calming measures, there were a total of 102 accidents involving pedestrians walking straight. However, after the installation of these road safety measures, the number of accidents increased slightly to 104, marking a modest 2% increase in incidents.

It's worth noting that while there was a slight overall increase, some road segments exhibited significant improvements in pedestrian safety. For instance, the Lideta interchange to AU Junction (LidetaTsebel) Road segment experienced a remarkable reduction in accidents involving walking pedestrians. The number of incidents decreased from 22 before the implementation of speed humps with rumble strips to just 8 afterward, reflecting a substantial enhancement in road safety.

Similarly, the Mekanisa Abo RA to Mekanisa Bridge Road segment saw a significant change, with the number of accidents reduced from 16 to 6, representing a noteworthy 10% reduction in pedestrian-related accidents. Notably, six road segments experienced an increase in the number of accidents involving walking pedestrians, ranging from 12 to 4.

It's important to mention that road segments where there were no incidents of pedestrian accidents both before and after the implementation of speed humps were not depicted in Figure 4-14. These findings illustrate the varied impact of speed humps with rumble strips on pedestrian safety across different road segments, with some areas showing substantial improvements while others experienced slight increases in incidents.

4.2.5. Change in Accidents Involving Public Transport vehicles

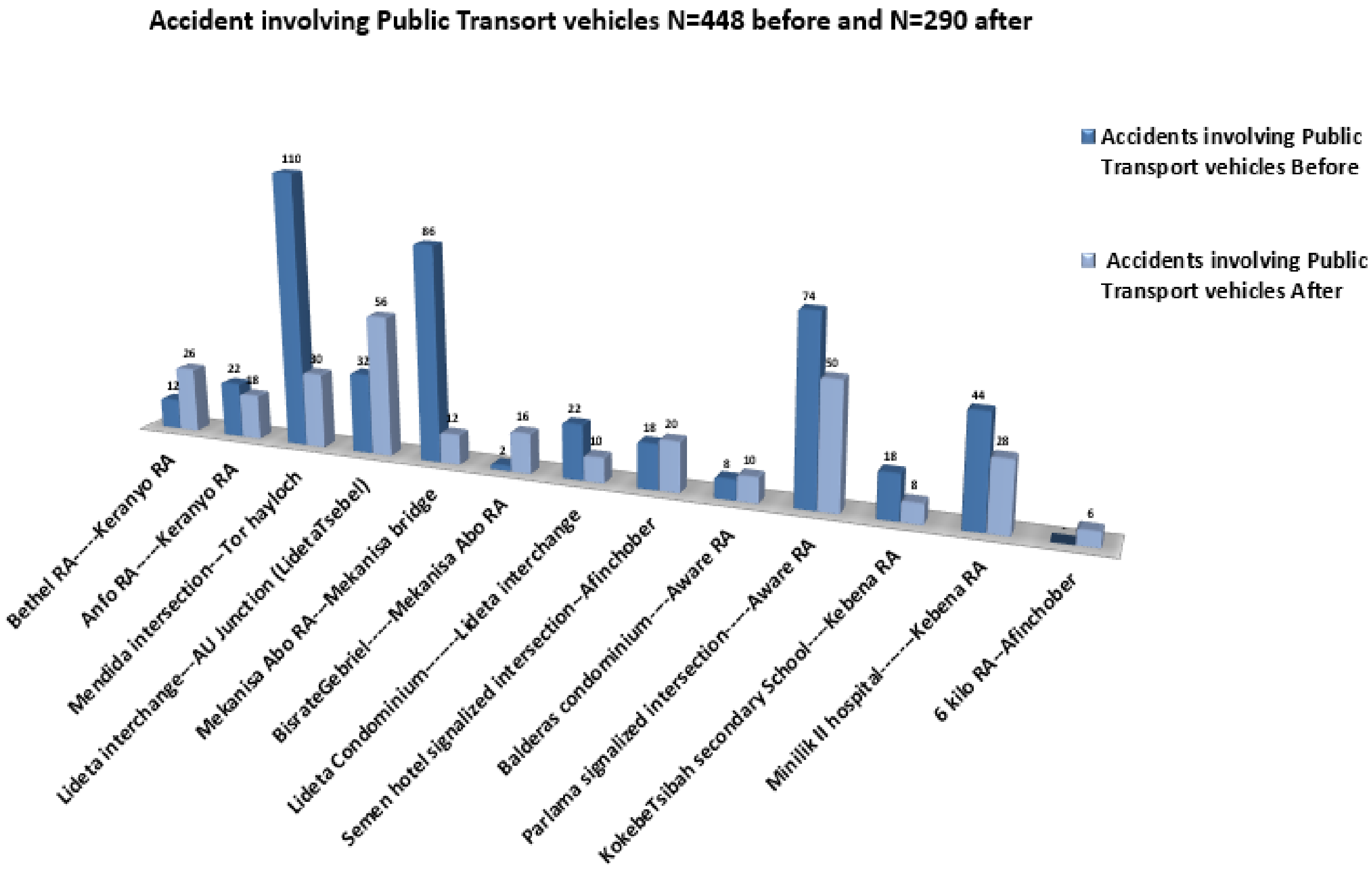

Figure 4 - 16: Accidents involving Public Transport vehicles before and after implementation speed humps with rumble strips

Prior to the implementation of speed humps with rumble strips, there were a total of 448 accidents involving public transport vehicles, which include taxis and buses. However, following the installation of speed humps with rumble strips, the number of accidents involving public transport vehicles decreased significantly to 290. This reduction amounts to a substantial 35% decrease in the number of accidents involving public transport vehicles, indicative of the positive impact of the implemented road safety measures.

The most substantial change was notably observed in the Mendida intersection to Tor hayloch Road segment, where the number of accidents involving public transport vehicles dropped dramatically. Prior to the installation of the speed humps with rumble strips, this segment experienced 110 crashes involving public transport vehicles. After the implementation of the speed humps with rumble strips, this number decreased significantly to just 30 accidents, showcasing a substantial improvement in road safety. These results underscore the effectiveness of speed humps with rumble strips in reducing accidents involving public transport vehicles and enhancing safety on the road.

4.3. Statistical Analysis of findings

4.3.1. Summary of T-test Results

To determine the statistical significance of the findings from each investigation, a rigorous process was undertaken. T-tests were employed as a robust statistical tool to determine whether the observed results were indeed statistically significant or if they lacked the requisite level of confidence for conclusive outcomes. The study utilized SPSS 25 to conduct these T-tests, ensuring a rigorous and reliable approach to the analysis.

A. Summary of T-test Result for Traffic Speed

For the examination of traffic speed, the study conducted several paired t-tests to thoroughly assess different aspects. The first T-test was conducted for traffic speed before the humps and on the humps. The second T-test was conducted for traffic speed on the humps and after the humps the final T-test was conducted for traffic speed before the humps and after the humps for all selected(available in all speed reading points for all road segments) vehicle classifications.

Table 4.5. Summary of T-test results for traffic speed

Paired Samples Test										
Vehicle Classifications	Pairs	Paired Differences					t	df	Sig. (2-tailed) (P-value)	Remarks
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference					
					Lower	Upper				
Car	Before 20m of speed hump -- At the speed hump	6.700	5.196	1.441	3.560	9.840	4.649	12	0.001	Statistically significant
	At the speed hump -- After 20m of speed hump	-8.731	3.448	0.956	-10.814	-6.647	-9.130	12	0.000	Statistically significant
	Before 20m of speed hump -- After 20m of speed hump	-2.031	3.840	1.065	-4.351	0.290	-1.907	12	0.081	Statistically significant
4WD(4-wheel drive)	Before 20m of speed hump - At the speed hump	6.569	4.927	1.366	3.592	9.546	4.808	12	0.000	Statistically significant
	At the speed hump - After 20m of speed hump	-9.277	3.189	0.885	-11.204	-7.350	-10.488	12	0.000	Statistically significant
	Before 20m of speed hump - After 20m of speed hump	-2.708	3.685	1.022	-4.935	-0.481	-2.649	12	0.021	Statistically significant
Large Truck	Before 20m of speed hump - At the speed hump	6.100	4.066	1.128	3.643	8.557	5.410	12	0.000	Statistically significant
	At the speed hump - After 20m of speed hump	-5.631	6.308	1.750	-9.443	-1.819	-3.218	12	0.007	Statistically significant
	Before 20m of speed hump - After 20m of speed hump	0.469	6.189	1.717	-3.271	4.209	0.273	12	0.789	Statistically insignificant

The T-test results presented in the table shown important findings regarding traffic speeds in different vehicle classifications. the statistical significance of the T-test for traffic speeds was established for all vehicle classifications and all three pairs, except for large truck in the pairs of "Before 20m of speed hump" and" After 20m of speed hump."

B. Summary of T-test Result for Traffic Accident

The findings from each of the investigations had to be checked if they are statistically significant or were simply not enough as conclusive results. T-tests were used to check if each the results obtained were statistically significant or not. The first T-test conducted was for total EANs before implementation of speed humps with rumble strips and after implementation of speed humps with rumble strips. The second T-test was conducted for total pedestrian accidents before implementation of speed humps with rumble strips and after implementation of speed humps with rumble strips. The third T-test was conducted for Pedestrian Accidents Crossing on Roadway before implementation of speed humps with rumble strips and after implementation of speed humps with rumble strips. The fourth T-test was conducted for Pedestrian Accidents Walking Strait before implementation of speed humps with rumble strips and after implementation of speed humps with rumble strips. The last T-test was done for Accidents involving Public Transport vehicles before implementation of speed humps with rumble strips and after implementation of speed humps with rumble strips.

Table 4.6. Summary of T-test results for traffic accidents

Paired Samples Test									
Pairs(Before with After)	Paired Differences					t	df	Sig. (2-tailed) (P-value)	Remarks
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference					
				Lower	Upper				
Change in Total Accidents	28.769	25.133	6.971	13.581	43.957	4.127	12	0.001	Statistically significant
Change in Total Pedestrians Accidents	13.385	21.298	5.907	0.515	26.255	2.266	12	0.043	Statistically significant
Change in Crossing Pedestrian Accidents on Roadway	19.231	16.053	4.452	9.530	28.931	4.319	12	0.001	Statistically significant
Change in Pedestrian Accidents Walking Strait	-0.154	7.978	2.213	-4.975	4.667	-0.070	12	0.946	Statistically insignificant
Change in Accidents involving Public Transport vehicles	12.154	31.701	8.792	-7.003	31.311	1.382	12	0.192	Statistically insignificant

In assessing the impact of road safety measures, it's essential to go beyond absolute numbers and delve into the statistical significance of the observed changes. To achieve this, the research employed T-tests to evaluate whether the changes observed in the before-and-after studies were statistically significant. The results of these tests had shown that, among the studied variables three exhibited statistically significant changes and two shows statistically insignificant changes. Significant differences were observed in the Total Accidents, Total Pedestrians Accidents and Crossing Pedestrian Accidents on Roadway. However, no statistically significant differences were found in Pedestrians Walking Straight and public transport users.

4.3.2. Regression Analysis

These models shall be suggested for the use of practicing engineers. This type of relationship can be used as a tool for density of hump for a particular 85th Percentile Crossing speed. A linear regression modeling between density and the crossing speeds is suggested since, linear models are considered as simple for the designers as it involves less complexion. The aim here is to obtain a statistical relation between density of speed hump and crossing speeds. Also, the density of speed hump is the ratio of number of speed hump and road segment length. Considering the 85th percentile crossing speeds, noted from field as independent variable a linear regression model is developed for Speed hump density for the data given in Table: 4. below.

Table 4.7. Variables for linear regression model

Frequency of Speed hump(No)	9	6	12	3	2	7	3	2	3	3	2	2	2
Road Segments Length(km)	1.8	2.8	2.4	0.9	1	1.7	0.6	0.9	1	1.4	0.4	0.8	0.7
Speed hump density(No/ Km)	5	2.2	5	3.5	2	4.1	5.5	2.4	3	2.1	5.7	2.7	2.9
85th Percentile Crossing speed (kmph)	23	18.3	39	23.3	21.3	29	27.6	17.1	16.7	17.7	20.4	20.5	20.6

SPSS REGRESSION ANALYSIS OUTPUT

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	85th Percentile Crossing speed (kmph)b	.	Enter

a. Dependent Variable: Speed hump density(No/ Km)

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.602[a]	.362	.304	1.1304

a. Predictors: (Constant), 85th Percentile Crossing speed (kmph)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.977	1	7.977	6.244	.030[b]
	Residual	14.055	11	1.278		
	Total	22.032	12			

a. Dependent Variable: Speed hump density(No/ Km)

b. Predictors: (Constant), 85th Percentile Crossing speed (kmph)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.556	1.237		0.450	.662
	85th Percentile Crossing speed (kmph)	0.132	0.53	.602	2.499	.030

a. Dependent Variable: Speed hump density(No/ Km)

From the above data a linear regression model is fitted by considering number of speed hump/length of road segment ratio as dependent variable and 85th Percentile Crossing speed as independent variable, which resulted in the following equation with R2 value 0.362.The value R2 = 0.362 indicates that nearly 36% of the variability in the response variable (85th percentile crossing speeds) is accounted for by the predictor variable (Speed hump density). The value of R2 indicates a moderate linear relationship between Speed hump density and 85th percentile crossing speeds.

$$y = 0.132X + 0.556$$

Where y is the dependent variable which is Speed hump density and x is the independent variable that is 85th percentile crossing speed. Based on the R-square value obtained which is considered as reasonable for a regression model, From the analysis, the model has a logical explanation for the effect of the independent variable in predicting Speed hump density. The positive signs of the independent variables 85th Percentile Crossing speed mean that the increases of 85th Percentile Crossing speed increase the Speed hump density.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

- The results obtained from a speed survey conducted on most of the road segments under study confirm the effectiveness of speed humps with rumble strips in slowing down vehicular speeds. Specifically, the survey indicated that 85th percentile speeds were maintained below the speed limits of 30km/h by a considerable percentage at different points along the road segments: 46% 20 m before the speed hump, 92% at the speed hump, and 23% 20 m after the speed hump, across the total selected road segments.

- The T-test results for traffic speeds were statistically significant for all Variables (car, 4WD and Large Truck) and for all three pairs of measurements, except in the case of the Large Truck, specifically for "Before 20m of the speed hump" and" After 20m of the speed hump" pair. This suggests that the variance in spot speed readings concerning the location of the speed hump does not significantly affect changes in traffic speed. The study further highlights that even when operating speeds exhibit a temporary increase immediately after driving over a speed hump, the spacing between two consecutive humps and the presence of intermediate rumble strips effectively prevent excessively high speeds, ensuring that vehicles slow down as they approach speed humps.

- The study shown a 31% reduction in Total Equivalent Accidents (EANs), a 24% reduction in total pedestrian accidents, a 54% reduction in pedestrian accidents involving crossing on the roadway, a 2% increase in pedestrian accidents involving walking straight and a 35% reduction in accidents involving public transport vehicles after the implementation of speed humps with rumble strips.

- Along with T-test results, it can be concluded that speed hump with rumble strips are effective in reducing accidents. When we can see the impact of speed hump with rumble strips on pedestrian safety the results also shows a significant change in the before-and-after study. With respect to pedestrian accidents by main activity speed hump with rumble strips the result also shows a significant change it can be concluded that speed hump with rumble strips are effective in reducing accidents Pedestrians Crossing on Roadway. This affirms that speed hump with rumble strips help in safe Crossing on Roadway. This means pedestrians can Cross relatively easier and are safer than Crossing on the roadway without speed hump with rumble strips.

- A T-test carried out on Pedestrians Accident Walking Strait in the before-and-after study indicated no significant change. Using results of this T-test, we can conclude that, speed hump with rumble strips, in this case, do not effect a significant change in reducing Pedestrians crashes Walking Strait. A T-test carried out on public transport study indicated no significant change. Using results of this T-test, we can conclude that, speed hump with rumble strips, in this case, do not effect a significant change in reducing public transport crashes on the road. Although the reduction is statistically important, it is important to understand the change. Although the study looked at accidents involving public transport, it did not look at the state of roadworthiness of these vehicles. This is very important to note as some accidents could have occurred because of mechanical failures attributed to vehicles that are not roadworthy. This presents a limitation on the conclusiveness of the study.

- Regression analysis used to produce the best relationship between density of speed hump and 85th Percentile Crossing speeds of the vehicles. Generally, the simple linear regression model that include one independent variable (85th Percentile Crossing speed) .This model is very useful and can be used for speed reduction evaluations based on speed hump density that can be used by highway and traffic engineers. The signs of the correlation coefficients in the regression model are as expected. The density of speed hump shows a positive correlation with 85th Percentile Crossing speed.

5.2. RECOMMENDATIONS

For future study into Examining the safety performance of speed humps with rumble strips may include the following point:

- The accident database maintained by the police stations is notably disorganized, which greatly compromises its accuracy in depicting crash events. Additionally, the data reporting process is marked by inadequacies, with a substantial portion of the recorded data lacking essential details concerning the circumstances of the accidents. These critical details include the precise location of the accident, the factors contributing to the crash, collision diagrams, and more. Consequently, these limitations have far-reaching effects on the ability to accurately compile statistical reports on the patterns of traffic accidents. Moreover, it poses a significant challenge in discerning the primary causes of these accidents, as the insufficient and disorganized data hinders comprehensive analysis and understanding of road safety issues.

- There was a lack of traffic speed data before speed humps with rumble strips were implemented. It is better to incorporating information on traffic speed data before and after implementation of speed humps with rumble strips. Because the data is important to determine the effectiveness of implemented speed humps with rumble strips with respect to speed reduction.

- Additionally, assessing the quality of road infrastructure is crucial, as it directly affects how both pedestrians and vehicles use the road. In cases where sidewalks are lacking or in poor condition, pedestrians are often forced to walk on the roadway, increasing the potential for accidents.

- While this kind of traffic calming, involving the use of speed humps with rumble strips, may be more expensive than passive mitigation methods such as educational campaigns, it is still a cost-effective option compared to alternatives like roundabouts or speed tables. There is no one-size-fits-all solution for curbing speeding, and the use of physical barriers and proactive mitigating measures represents just one approach. Moreover, it doesn't always guarantee a fundamental shift in how drivers perceive the road. The municipality of Addis Ababa has an excellent opportunity to allocate funds to educational campaigns aimed at raising awareness among road users.

- Address the potential impact of drivers' cognitive abilities on their behavior and reactions to traffic calming measures.

- Conduct further research to validate the findings of this study.

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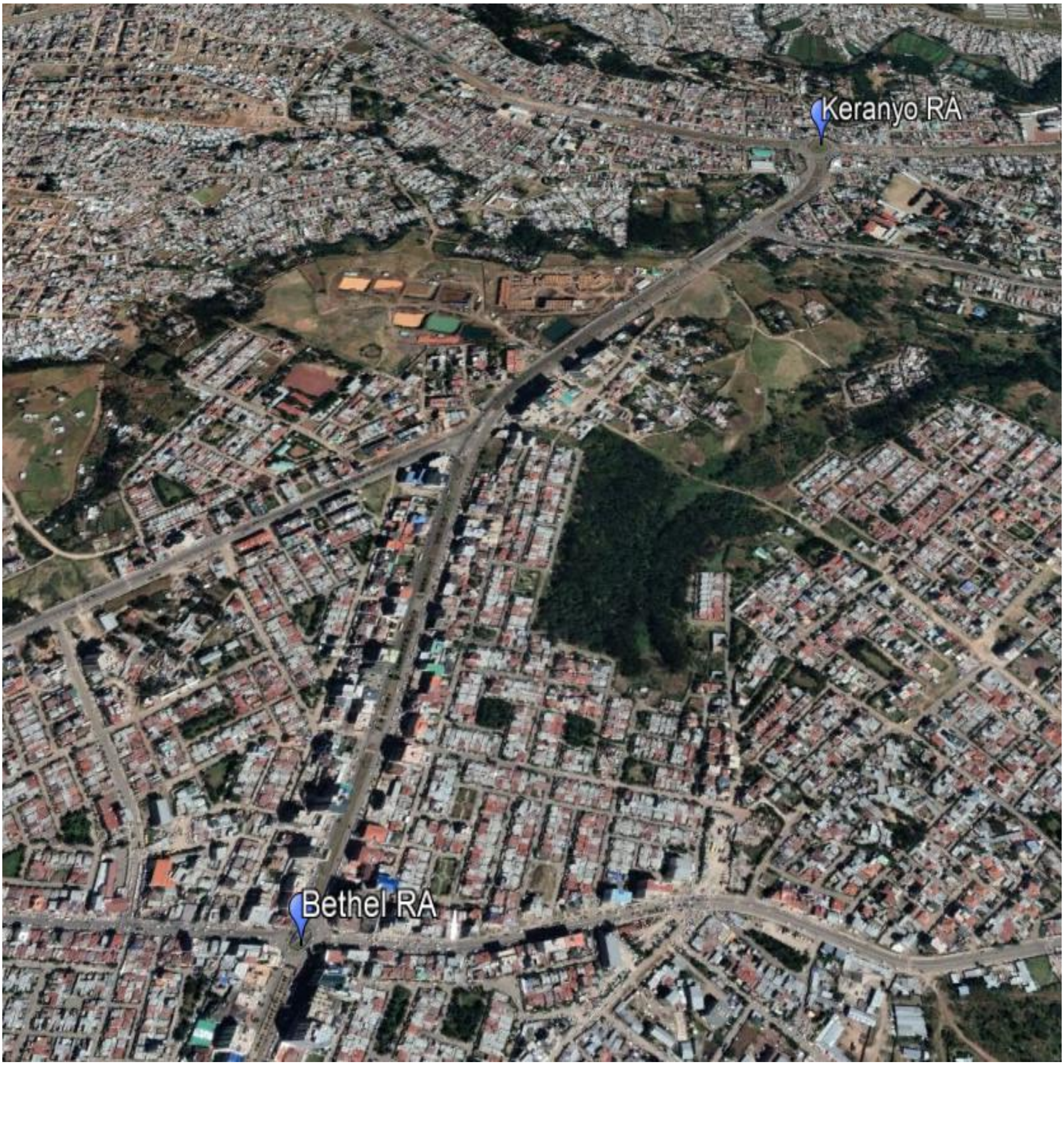
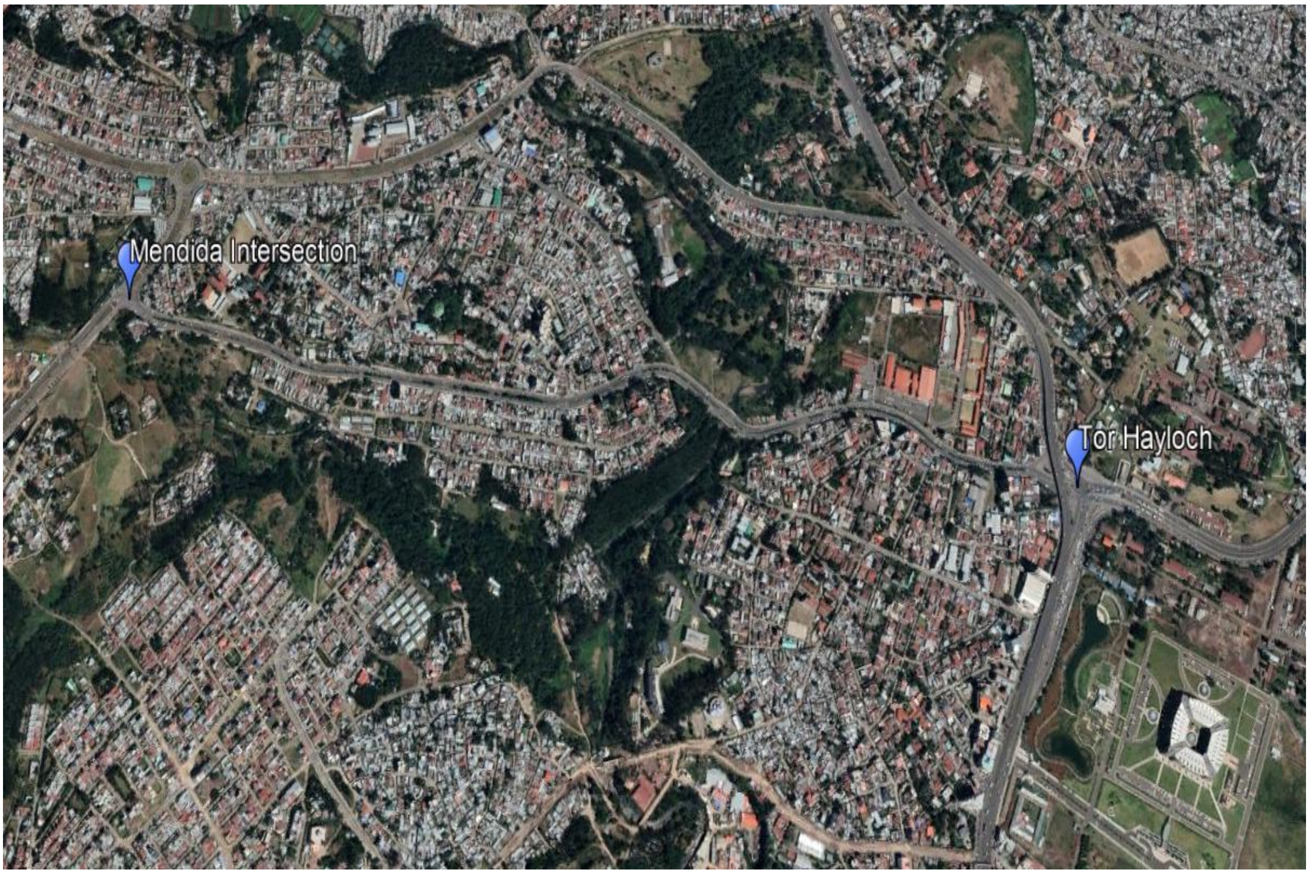
ANNEX

Relative Location Map of Selected Road Segments




Anfo RA
Keranyo RA

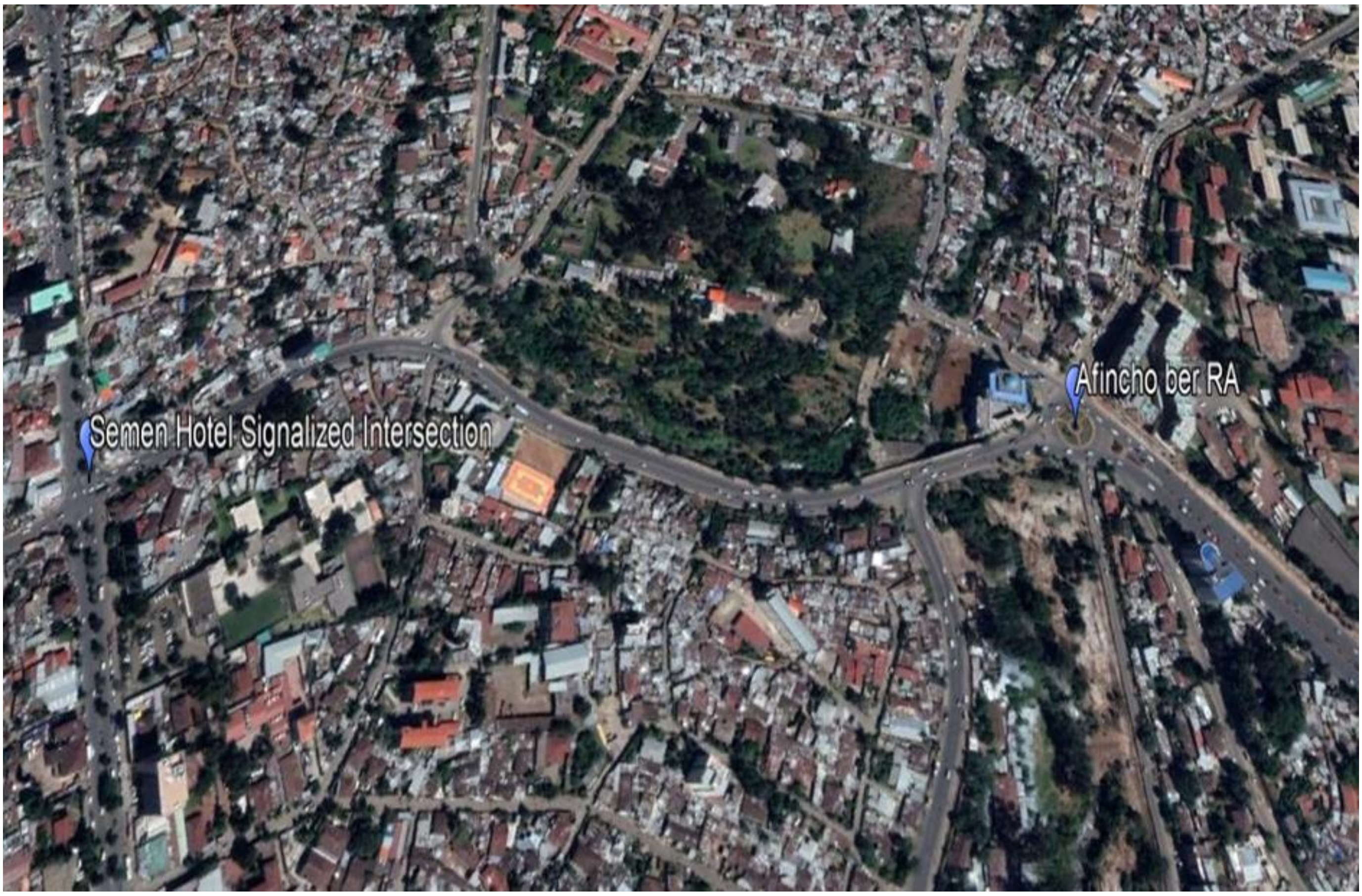

Mendida Intersection
Tor Hayloch


Lideta Interchange
AU Junction (Lideta Tsebel)

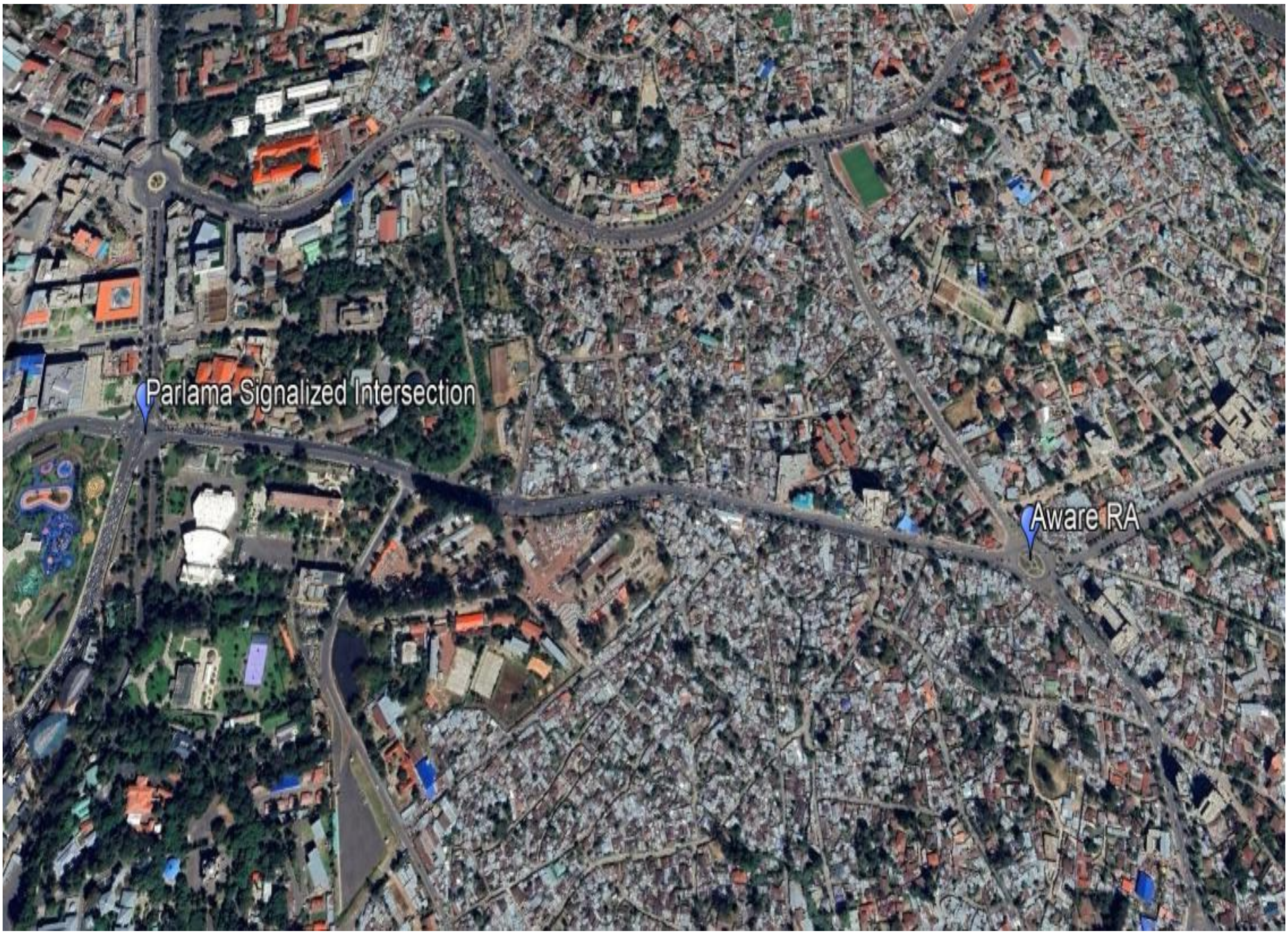

Mekanisa Abo RA
Mekanisa Bridge


Bisrate Gebriel
Mekanisa Abo RA


Lideta Condominium
Lideta Interchange


Semen Hotel Signalized Intersection
Afincho ber RA


Aware RA
Balderas Condominium


Parlama Signalized Intersection
Aware RA


Kebena RA
Kokebe Tsibah Secondary School


Minilik II Hospital
Kebena RA


Afincho ber RA
6 Kilo RA