TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

Thesis No.: T02/070

The Study of Effect of Humps in Vehicular Movement (A Case Study of Kathmandu Valley)

by

Abhash Poudel

A THESIS

SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN TRANSPORTATION ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

LALITPUR, NEPAL

FEBRUARY, 2017

COPYRIGHT

Head

Department of Civil Engineering

Pulchowk Campus, Institute of Engineering

Lalitpur, Kathmandu

Nepal

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF CIVIL ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"The Study of Effect of Humps in Vehicular Movement (A Case Study of Kathmandu Valley)"** submitted by Abhash Poudel in partial fulfillment of the requirements for the degree of Master in Transportation Engineering.

____
Supervisor: Anil Marsani
Program Coordinator
M. Sc. in Transportation Engineering
Pulchowk Campus

____
External Examiner: Rajendra Raj Sharma
Superintendent Engineer (SuE)
Government of Nepal

____
Committee Chairperson: Anil Marsani
Program Coordinator
M. Sc. in Transportation Engineering
Pulchowk Campus

Date: 14th March, 2017

ABSTRACT

Road accident is a major problem in the developing countries like Nepal. The unlimited high speed results in crashes. Hence the speed humps are used. But the improper geometry further leads to more crashes. Nepal Road Standard has given the geometrical criteria for speed humps, which are still not followed. No any scientific and precise relation has been developed between speed and hump parameters for fixing accurate geometry. The objective of this thesis is to provide a rational and precise relationship of safe speed of vehicles with various parameters of hump such as length, width, arc length and area to width.

All the analyses were made using Microsoft Office Excel 2010. The works showed that statically significant regression relationships could be established only between hump-crossing speed and hump geometry characterized by area to width ratio. The area to width ratio decreased linearly as the speed increased. Besides this, the hump section had less speed than the normal section, both for bikes and cars. Furthermore, the speed of bikes in the roads of Kathmandu was found out to be more than that of cars.

This thesis is important, mainly for the planners and designers. With the help of relationship between speed and hump parameters, design of hump would be precise and easier for planners.

Keywords: humps, area to width ratio, 85^{th} pecentile speed, regression

ACKNOWLEDGEMENTS

I would like to begin by thanking the Institute of Engineering, Pulchowk for giving me the opportunity of pursuing my Master degree in Transportation Engineering. I am sincerely grateful to my thesis supervisor Anil Marsani for his continuous support and guidance during the thesis work. Without his supervision and constant help this thesis would not have been possible.

I am grateful to Anil Jayswal and Susan Shrestha for providing me camera, and Deependra Pathak for helping me record the video. I am also thankful to my brother Rabin Adhikari for his help in data collection of Saatdobato and Yatayat.

I would also like to thank my father Kabiraj Poudel for guiding and helping me at every stage of the thesis work.

Abhash Poudel

070/MST/252

FEBRUARY, 2017

TABLE OF CONTENTS

COPYRIGHT…………………………………………………………………………………Error! Bookm

ABSTRACT ……………………………………………………………………………..3

ACKNOWLEDGEMENT………………………………………………………………5

TABLE OF CONTENTS ……………………………………………………………….6

LIST OF TABLES………………………………………………………………………8

LIST OF FIGURES……………………………………………………………………..9

LIST OF SYMBOLS AND ABBREVIATIONS………………………………………..10

CHAPTER ONE: INTRODUCTION……………………………………………...11

1.1 Background 11

1.2 Objectives 11

1.3 Statement of problem.. 12

1.4 Limitations 12

1.5 Organization of the report.. 12

CHAPTER TWO: LITERATURE REVIEW……………………………………….14

2.1 Definition of Speed Humps 14

2.2 Effects of speed breakers in vehicle movement.................................. 15

2.3 Geometry of Speed Breaker in Kathmandu Valley............................. 17

CHAPTER THREE: METHODOLOGY…………………………………………….18

3.1 Population Sample.. 18

3.2 Source of Data... 18

3.3 Site Selection and Data Collection, and Extraction 18

3.3.1 Bishalchok Site 19

3.3.2 Yatayat Site.. 19

3.3.3 Jawlakhel Site 20

3.3.4 Satdobato Site 21

3.3.5 Buddhanagar Site 21

3.3.6 Chakupat site 22

3.3.7 Jhamsikhel site 23

3.3.8 Talchikhel site 23

CHAPTER FOUR: DATA ANALYSIS 24

4.1 Analysis of Hump Parameters 24

4.2 85th percentile Speed Chart at Different Sites 24

4.2.1 Bishalchok site 24

4.2.2 Yatayat site 25

4.2.3 Jawlakhel site 26

4.2.4 Saatdobato site 26

4.2.5 Chakupat site 27

4.2.6 Buddhanagar site 28

4.2.7 Jhamsikhel site 28

4.2.8 Talchikhel site 29

4.3 Analysis of Parameters that affect Velocity over hump 30

4.3.1 R-square value and equation of Velocity of Cars and Hump Parameter 32

4.3.2 R-square value and equation of Velocity of bikes and Hump Parameter 34

4.4 Analysis of Reduction of Speed over Hump 35

4.5 Comparison of Speeds of Bikes and Cars 38

4.6 Analysis of maximum and minimum speeds 39

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION 40

APPENDIX A: DATA SHEETS 44

APPENDIX B: PHOTOGRAPHS 49

LIST OF TABLES

Table 2.1 Horizontal and Vertical Measures of Traffic Control ……………………..14

Table 4.1 Data for all hump parameters …………………………………………..24

Table 4.3.1 Table for Hump Parameter………………………………………………31

Table 4.3.2 Table for R-square value and corresponding velocity equations for cars……………………………………………………………………………………32

Table 4.3.3 Percentage error between calculated and normal data over hump 33

Table 4.3.4 Table for R-square value and corresponding velocity equations for bikes ………………………………………………………………………………….34

Table 4.3.5 Percentage error of speed for bikes over the hump ………………………35

Table 4.4.1 Comparison of speed between normal and hump section…………………36

Table 4.4.2 Observed and calculated percentage reduction of speed at hump……. **37**

Table 4.5 Observed and calculated percent reduction of speed of cars with respect to Bikes………………………………………………………………………………… 38

Table 4.6 Table for minimum speed over hump and maximum speed in normal section……………………………………………………………………………. **39**

LIST OF FIGURES

Figure 2.1 Size of Speed Breaker recommended by Department of Roads 15

Figure 2.3 Un-uniformity in Hump Geometry Standard in Kathmandu 17

Figure 3.3.1 Bishalchowk Site..19

Figure 3.3.2 Yatayat Site 20

Figure 3.3.3 Jawlakhel Site 20

Figure 3.3.4 Satdobato site 21

Figure 3.3.5 Buddhanagar...22

Figure 3.3.6 Chakupat site 22

Figure 3.3.7 Jhamsikhel site 23

Figure 3.3.8 Talchikhel site 23

Figure 4.2.1 85th percentile speed of bikes and cars at Bishalchowk 25

Figure 4.2.2 85th percentile speed of bikes and cars at Yatayat 25

Figure 4.2.3 85th percentile speed of bikes and cars at Jawlakhel 26

Figure 4.2.4 85th percentile speed of bikes and cars at Satdobato 27

Figure 4.2.5 85th percentile speed of bikes and cars at Chakupat...........................27

Figure 4.2.6 85th percentile speed of bikes and cars at Buddhanagar 28

Figure 4.2.7 85th percentile speed of bikes and cars at Jhamsikhel 29

Figure 4.2.8 85th percentile speed of bikes and cars at Talchikhel 29

Figure 4.3.1 Linear correlation chart for cars 33

Figure 4.3.2 Linear correlation chart for bikes...35

LIST OF SYMBOLS AND ABBREVIATIONS

A	Area
H	Height
Kmph	Kilometer per hour
m/sec	meter per second
L	Length
m	Meters
W	Width
DOR	Department of Roads
HPU	Highway Planning Unit

CHAPTER ONE: INTRODUCTION

1.1 Background

It is very important to control vehicular speed in traffic management. There are two ways of speed limitation-Physical limitation and psychological limitation. Psychological compulsion, includes the various devices which create the driver psychological need to reduce the speed - the effect of narrowing or a curvature of movement trajectory; the effect of break of movement trajectory, a special marking which becomes more frequent; chokers; rumble strips with increasing frequency of sound influence (Vrubel, 2008). The second way is the physical limitation which includes traffic calming devices, such as speed humps, raised crosswalks, raised intersections etc. Bunte (2000) observes that usual objectives that have been observed for traffic calming programs were to slow down traffic speeds, reduce cut-through traffic, increase safety of pedestrians, bicyclists and vehicles; reduce traffic noise; and improve aesthetics of neighborhoods.

In this thesis, an impact of speed humps on vehicular movement is analyzed. Speed humps are defined as raised areas over the road surface, which are installed over the whole or partial road width, and present a physical measure for reducing travel speed (Gitelman and Hakkert, 2006). Speed humps are generally parabolic in nature (Indian road congress, 1998). In particular, speed humps influence the driver and his automobile by visual impact and physical (shock) impact (Vrubel, 2008). Therefore, reliable geometric design should be made so that speed can be reduced without creating any discomfort on the driver. However, no proper geometrical criteria have been followed in design. Though speed control humps are commonly used, well accepted design guidelines are not readily available (Sahoo, 2010).In this work, a geometrical design process of hump is mentioned relating it with speed of vehicles over hump, so as to assist the policy makers in developing a reliable and standard hump geometry.

1.2 Objectives

The objective of this thesis is categorized as general objective and specific objective. The general objective includes:

- to analyze the speed reduction of bikes and cars at hump stretch with respect to normal stretch.
- to compare speeds of bikes and cars at normal stretch and hump stretch

The specific objective includes:

- to analyze the parameters that affect speed; that is to find the relation between speed and geometry.

1.3 Statement of problem

Road crash is a major issue in present context. Crashes occur mainly due to increased speed of vehicles. Hence, speed humps may be one of the mechanisms of controlling speeds, and hence crashes. Likewise, in Kathmandu, haphazardness in geometry of speed humps is serious problem. There are no properly designed humps, which are destroying the aesthetic beauty of roads. The improperly constructed and having no fixed geometry leads to risk in crashes. There is no meaning of making such humps. The thesis intends to reduce the crashes thereby fixing appropriate geometry to humps.

1.4 Limitations

The humps in Nepal are not of standard size. The humps of width more than 3.7m as specified by NRS could not be found. Hence, the limitation is that the humps chosen had width less than the criteria. The result obtained doesn't incorporate the standard hump.

1.5 Organization of the report

This report consists of five chapters.

The first chapter gives the brief introduction to the topic. It includes background of the study, objectives, statement of problem and limitations of the study.

The second chapter is literature review. This chapter includes definition of speed humps, effect of speed breakers in vehicle movement, and geometry of speed breakers in Kathmandu valley.

The third chapter provides details on the methodology used to conduct this study. It includes the topics as: population sample, source of data, site selection, data collection and extraction.

The fourth chapter is analytical discussion. This chapter presents the analytical results obtained and brief discussion of them. This includes analysis of hump parameters, 85^{th} percentile speed chart at different sites, analysis of parameters that affect velocity, analysis of reduction of speed over humps, and comparison of speeds of bikes and cars.

The fifth chapter provides a comprehensive conclusion and recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1 Definition of Speed Humps

Traffic calming is one of the most important necessities of the present scenario. Different types of traffic calming methods and measures are being adopted in different conditions in different countries. Traffic calming measures may be horizontal and vertical. According to Highway Planning Unit (HPU) guidelines, the different types of traffic calming devices are illustrated below in table.

Table 2.1 Horizontal and Vertical Measures of Traffic Control

Vertical measures	Horizontal measures
Speed humps	Traffic circle
Speed bumps	Roundabout
Transverse bar or alert bar	Chicane
Speed table	Choker
Textured pavement	Central Island
Raised crosswalk	

Speed humps are the vertical calming measures. Speed humps are the traffic calming devices commonly installed to reduce traffic related accidents (Jain and Singh, 2013). The speed humps are also known as sleeping policeman. Speed humps are raised devices, parabolic in shape with minimum width of 3.7 m and height of 0.1 m at crown (DOR, 2006). The Department of road clarifies that no road humps shall be provided on road located in non-urban areas. They can be provided on slow speed roads (only on class IV roads) on some urban areas if their necessity is justified. The faces of humps shall be painted with 200 mm wide alternating black and white stripes at 45 degree slopes. The speed humps should be used in such places where the speed limit is less than 30kmph.

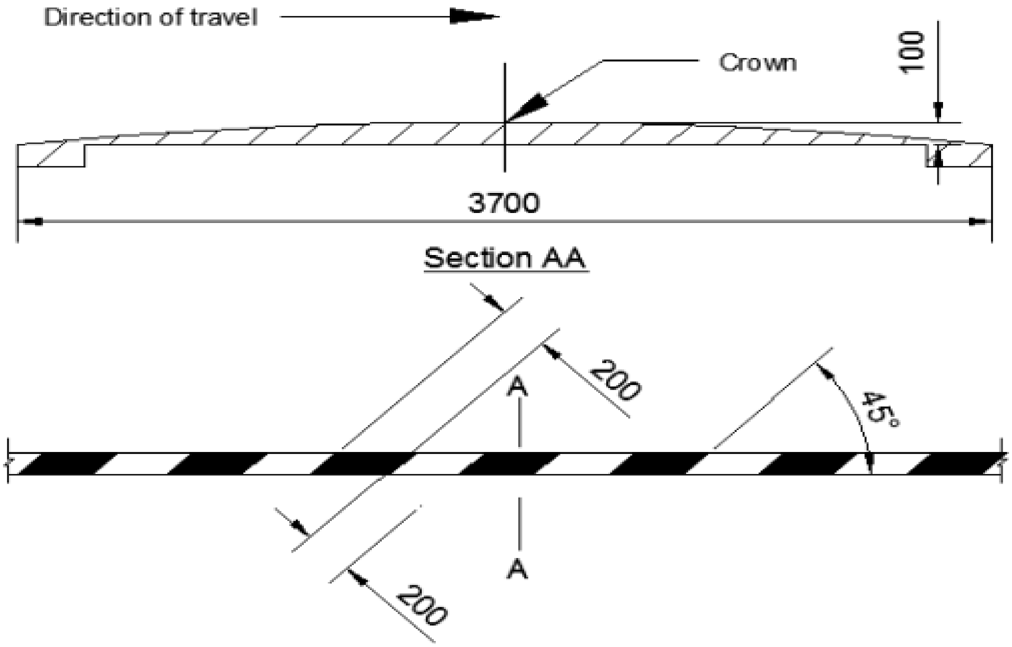

Figure 2.1 Size of Speed Breaker recommended by Department of Roads

2.2 Effects of speed breakers in vehicle movement

Road humps are designed to promote orderly movement and improved safety. However at certain locations such as approaches, sharp curves, accident prone locations, control of speed is necessary. Road humps, where permitted to be installed, provide visual, audible and traffic stimuli which alert drivers and cause them to slow down.The humps have got both the positive and negative properties.

- The positive property is that it reduces the vehicle speed. The design profiles of road humps have an impact on the speed of vehicles; the gentle the design profiles of the road humps especially in terms of height and slope, the higher the speed of vehicles near and at the road hump (Yaacob, 2013). Therefore, the higher the average height, the lesser will be the velocity. When the velocity becomes less, then there is automatic reduction of speed. When there is reduction in speed, there is reduction in number of crashes.

- The negative property is that it increases the journey time for buses and causes delay to emergency vehicles (Yaacob, 2013). The velocity is reduced by the speed hump, due to which the journey time is obviously increased.

Relating these two properties (speed reduction and time delay), Bunte (2000) captures the essence of the debate “Traffic calming and Emergency response: A competition of two public goods.” This property, that is speed reduction analysis (affecting traffic calming), is the general objectives of this thesis. Besides this, the comparison of speeds of cars and bikes near the hump and at normal stretch is also dealt in this thesis.

The specific objective of this thesis is related to the geometric design of hump. According to Sahoo (2010), no statistically significant relationships can be established between H/W ratio and the speed measurements, which signify that specifying only the width and height of a hump does not sufficiently enable the design engineers to effectively control the desired hump-crossing speed of traffic. An alternative quantitative indicator that can be utilized to characterize hump geometry is the area-to width ratio A/W, which can be seen as a measure of the average height provided over the base of hump. This has been indicated by Nair and Elangovan (2013); that is the speed decreases as the ratio of area to width increases. Vissim software was used to generalize the results. Therefore, area to width is the criteria that must be related with the speed of vehicles over the hump. Also, Fwa and Liaw (1994), in transport research record, say there is no correlation between speed and height to width ratio. In this thesis, an attempt is made to derive the general equation that relates velocity with geometry of hump. A number of research studies have been published which show the extent to which traffic calming features such as road humps reduce average traffic speeds (and 85th percentile speeds) – for example by Webster and Layfield (1996). But less is known about how these features affect the variation in speeds.The thesis tries to develop the relationship between different parameters like length, width, area to width, length to width and arc length with speed. From several literatures as mentioned above, it has been said that speed over the hump depends only upon area to width, Hence, the thesis checks whether the case is same in case of Kathmandu valley or not.

2.3 Geometry of Speed Breaker in Kathmandu Valley

In Kathmandu valley, no proper design standard of hump has been seen. Humps are scattered here-and-there without maintaining proper uniformity. “We concentrate on the width and height, but don’t have an exact measurement,” says Mukunda Raj Adhikari, spokesperson of the Department of Road (The Kathmandu Post, 2013). The picture below speaks of the present scenario. The exact criteria that are given by Nepal Road Standard are not followed. The speed humps are made in a haphazard way. Moreover, they are not in proper shape and size. No proper design and maintenance procedure is followed.

Figure 2.3 Un-uniformity in Hump Geometry Standard in Kathmandu Valley

The thesis also deals with the deviation in design of speed breakers from standard value that is given by NRS 2070. The deviation in width and height are basically dealt here.

CHAPTER THREE: METHODOLOGY

To achieve the objectives mentioned in chapter one, proper methodology needs to be formulated. This chapter explains the methods of site selection, data collection, extraction, analysis and interpretation.

3.1 Population Sample

This study involves analysis of speed over the speed humps. The bikes and cars are studied. Along with calculation of speed reduction of vehicles, the time delay at hump is also studied. Likewise, the length, width and height of each hump are calculated and the study is done to know which parameter affects the velocity. Around 400 data of bikes and 200 data of cars is taken at hump and normal section at each road to calculate 85th percentile speed.

3.2 Source of Data

Primary data collected for this study. All the required information is collected from the required section via video-graphic recording. The necessary data were extracted manually via video replaying. Other useful information was recorded on field sheets. No any secondary data was used during the study.

3.3 Site Selection and Data Collection, and Extraction

Firstly, a general survey is done within the Kathmandu valley for the selection of parabolic humps. Among the several parabolic humps that were found, the humps with regular and uniform geometry were chosen. Those humps with irregular geometry were neglected to get easiness and exactness in area calculation. The inner roads (gullies) were chosen. The road was selected such that 10 m section for hump , and another 10 m for normal section could be obtained. Overall, eight spots were chosen. The spots were Satdobato, Bishalchowk, Jawlakhel, Yatayat, Buddhanagar, Chakupat, Jhamsikhel and Talchikhel.

The video footage captured at site was replayed in the laboratory for the extraction of the required information. Following information was noted in excel sheets along with other manually collected data.

- Types of vehicles (motorcycles and cars).
- The time of entry and time of exit of vehicles at normal section.
- The time of entry and exit of vehicle at hump section.

The data for the hump was also taken; ie length, breadth, height and arc length of the hump.

3.3.1 Bishalchok Site

The Bishalchowk site is located one kilometer away from the ring road of Kathmandu valley. It is located in Lalitpur district. The hump is in good and working condition, which was installed one year back. Normal section and hump section were taken twenty meters away from each other.

Figure 3.3.1 Bishalchowk Site

3.3.2 Yatayat Site

The Yatayat site is also located in Lalitpur district. It is about fifty meters away from the ringroad of valley. The hump is in nice and working condition here. Distance between normal section and hump section was taken twenty meters.

Figure 3.3.2 Yatayat Site

3.3.3 Jawlakhel Site

This site is located just in front of British school. It lies within the ring road. The hump is in proper geometry and is in working condition. Distance between normal and hump section was taken twenty meters.

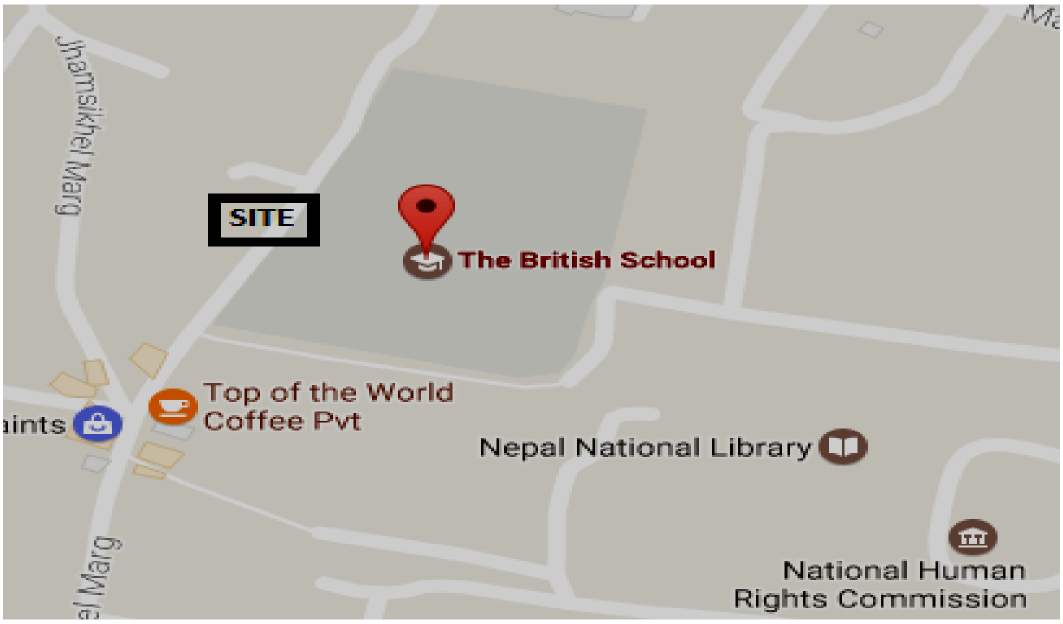

Figure 3.3.3 Jawlakhel Site

3.3.4 Satdobato Site

This site is about hundred meters away from ring road, which is in proper and working condition. The hump and normal section were taken twenty meters away from each other.

Figure 3.3.4 Satdobato site

3.3.5 Buddhanagar Site

The site lies inside ring road. It is about 500 m away from Sankhmul bridge. The normal and hump section were taken at a minimum separation of 20 m.

Figure 3.3.5 Buddhanagar

3.3.6 Chakupat site

This site is located within ringroad, about 200 m away from Mangalbazar, Patan. The site is in proper condition. The minimum separation between two sections was 20 m in minimum.

Figure 3.3.6 Chakupat site

3.3.7. Jhamsikhel site

This site is located within ring road in Kathmandu valley. The distance between normal and hump section was 20 m in minimum.

Figure 3.3.7 Jhamsikhel site

3.3.8. Talchikhel site

This site is located in Lalitpur district, about 100 m away from ring road. The hump is in proper and working condition. The distance between normal section and hump section is 20 m in minimum.

Figure 3.3.8 Talchikhel site

CHAPTER FOUR: DATA ANALYSIS

4.1 Analysis of Hump Parameters

Table 4.1 Data for all hump parameters

Hump	Places							
	Bishal Chowk	Yatayat	Jawlakhel	Satdobato	Buddha Nagar	chakupat	Jhamsikhel	Talchikhel
L, m	6.110	3.100	5.911	6.100	5.810	4.610	5.600	4.500
W, m	1.28	0.34	0.46	1.20	0.54	0.40	0.35	0.9
Arc, m	1.286	0.389	0.491	1.215	0.556	0.435	0.395	0.914
A, sq.m	0.0418	0.019	0.023	0.067	0.021	0.020	0.019	0.043

4.2 85th percentile Speed Chart at Different Sites:

4.2.1 Bishalchok site

The total count for bikes at hump and normal section of Bishalchowk were 403 and 401 respectively. The 85th percentile speed noted were 19 kmph and 33 kmph respectively.

The total count for cars at hump and normal section of Bishalchowk were 188 and 182 respectively. The 85th percentile speed noted were 15 kmph and 32 kmph respectively.

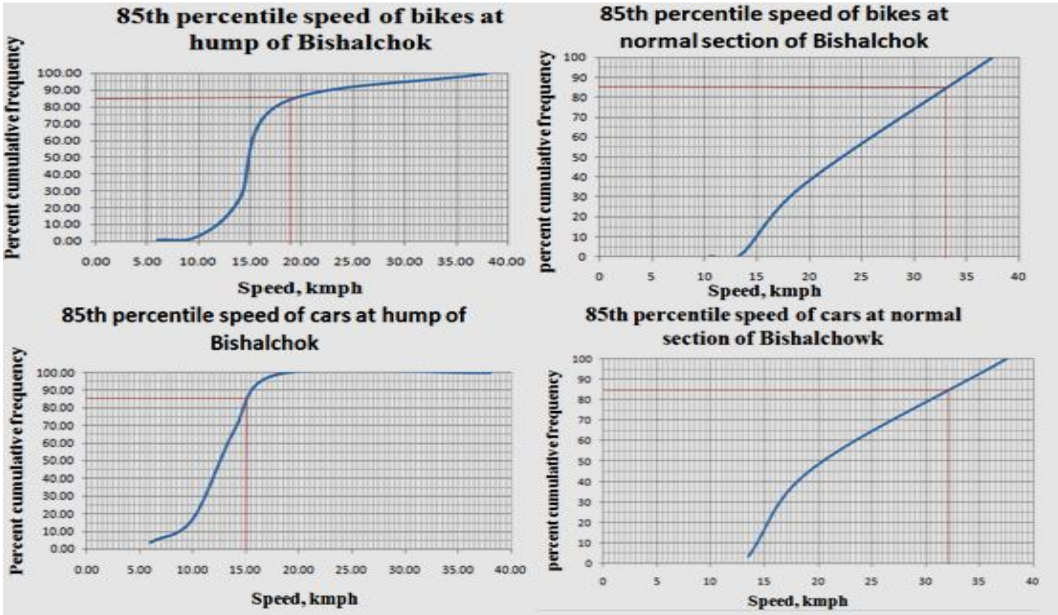

Figure 4.2.1 85th percentile speed of bikes and cars at Bishalchowk

4.2.2 Yatayat site

The total count for bikes at hump and normal section of Yatayat were 416 and 403 respectively. The 85th percentile speed noted were 14.2 kmph and 19 kmph.

The total count for cars at hump and normal section of Yatayat were 188 and 164 respectively. The 85th percentile speed noted were 10 kmph and 16 kmph respectively.

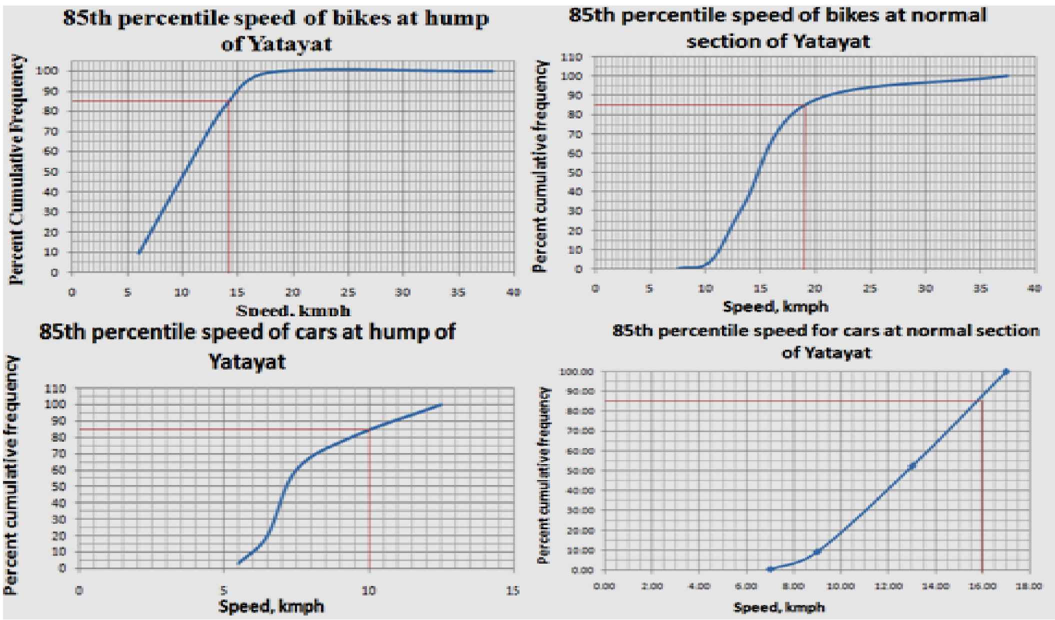

Figure 4.2.2 85th percentile speed of bikes and cars at Yatayat

4.2.3 Jawlakhel site

The total count for bikes at hump and normal section of Jawlakhel were 408 and 401 respectively. The 85th percentile speed noted were 14.5 kmph and 28 kmph respectively.

The total count for cars at hump and normal section of Jawlakhel were 189 and 201 respectively. The 85th percentile speed noted were 12 kmph and 19.5 kmph respectively.

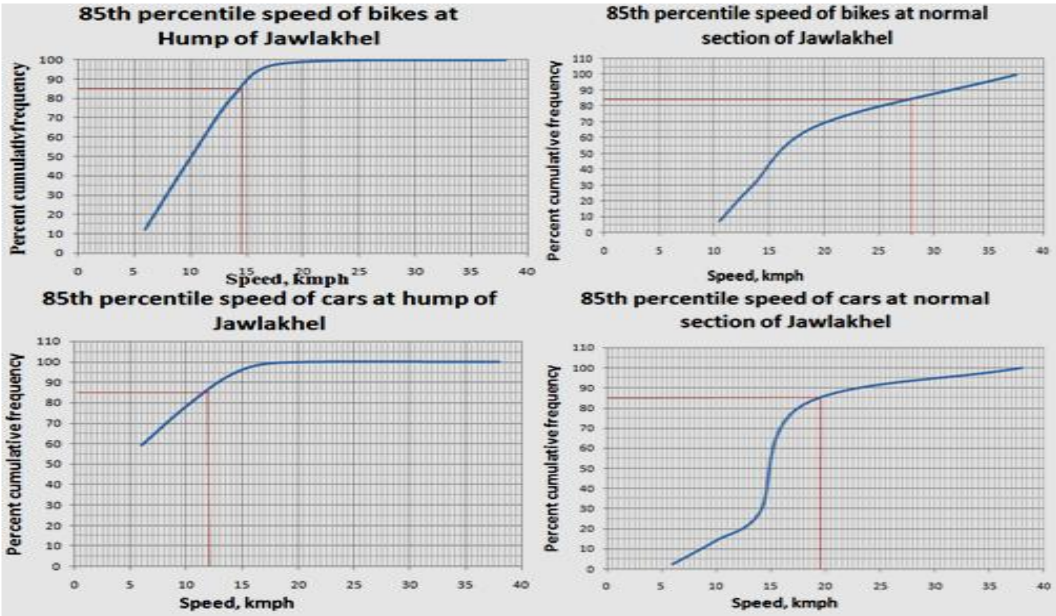

Figure 4.2.3 85th percentile speed of bikes and cars at Jawlakhel

4.2.4 Saatdobato site

The total count for bikes at hump and normal section of Satdobato were 395 and 401 respectively. The 85th percentile speed noted were 14 kmph and 17.2 kmph respectively.

The total count for cars at hump and normal section of Satdobato were 176 and 161 respectively. The 85th percentile speed noted were 11.2 kmph and 16 kmph respectively.

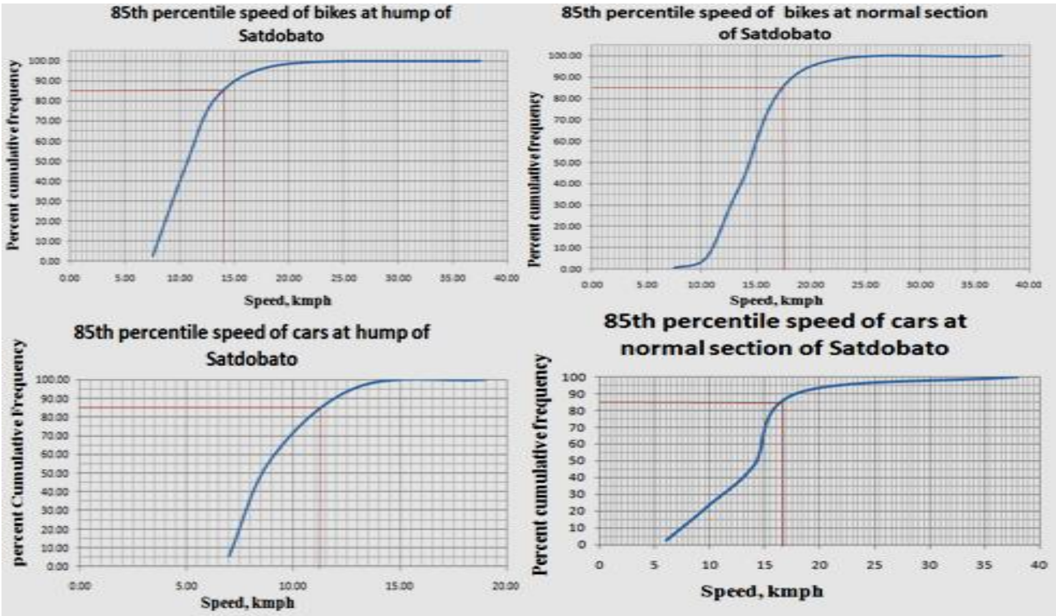

Figure 4.2.4 85th percentile speed of bikes and cars at Satdobato

4.2.5 Chakupat site

The total count for bikes at hump and normal section of Chakupat were 402 and 401 respectively. The 85th percentile speed noted were 14 kmph and 30 kmph respectively.

The total count for cars at hump and normal section of Chakupat were 177 and 187 respectively. The 85th percentile speed noted were 12.8 kmph and 23.5 kmph respectively.

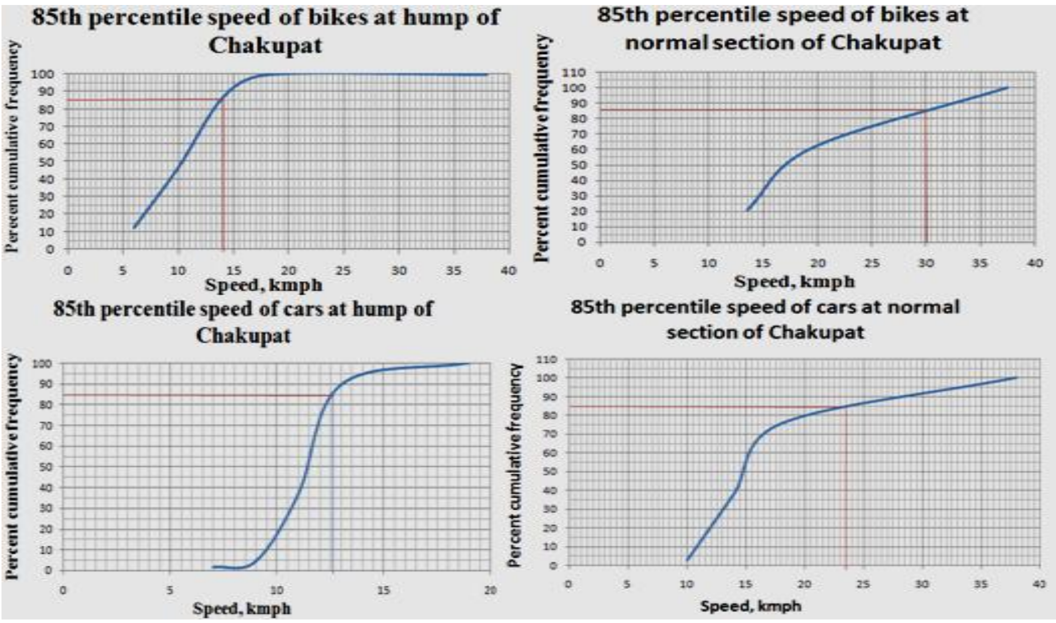

Figure 4.2.5 85th percentile speed of bikes and cars at Chakupat

4.2.6 Buddhanagar site

The total count for bikes at hump and normal section of Buddhanagar were 400 and 388 respectively. The 85th percentile speed noted were 18 kmph and 33 kmph respectively.

The total count for cars at hump and normal section of Buddhanagar were 203 and 196 respectively. The 85th percentile speed noted were 16 kmph and 32 kmph respectively.

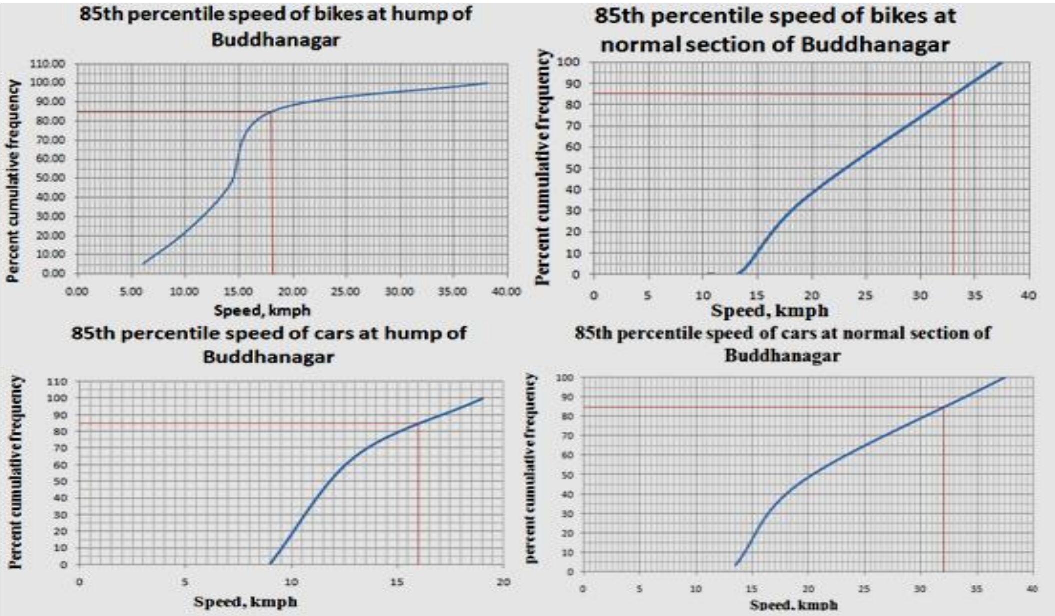

Figure 4.2.6 85th percentile speed of bikes and cars at Buddhanagar

4.2.7 Jhamsikhel site

The total count for bikes at hump and normal section of Jhamsikhel were 387 and 401 respectively. The 85th percentile speed noted were 13.5 kmph and 17.5 kmph respectively.

The total count for cars at hump and normal section of Jhamsikhel were 172 and 201 respectively. The 85th percentile speed noted were 12 kmph and 19 kmph respectively

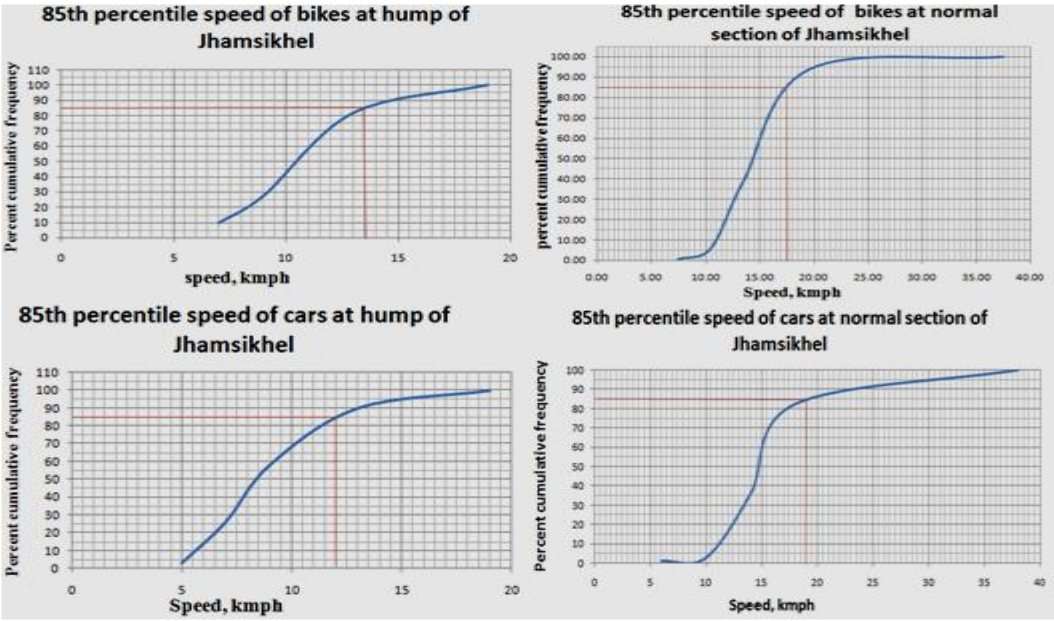

Figure 4.2.7 85th percentile speed of bikes and cars at Jhamsikhel

4.2.8 Talchikhel site

The total count for bikes at hump and normal section of Talchikhel were 395 and 387 respectively. The 85th percentile speed noted were 14.5 kmph and 31 kmph respectively.

The total count for cars at hump and normal section of Talchikhel were 195 and 186 respectively. The 85th percentile speed noted were 13.5 kmph and 28.5 kmph.

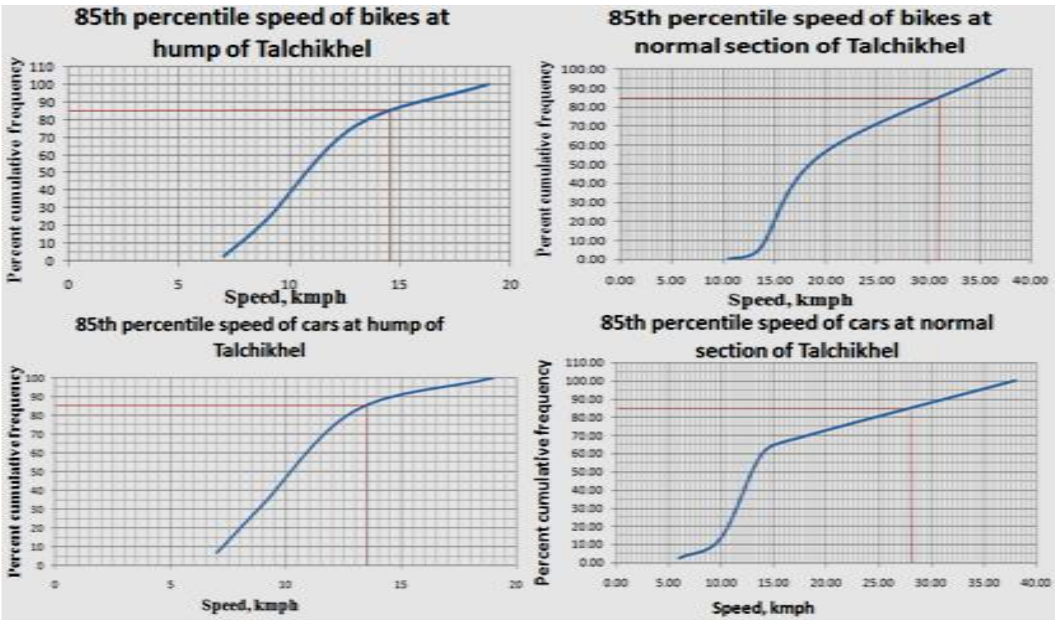

Figure 4.2.8 85th percentile speed of bikes and cars at Talchikhel

4.3 Analysis of Parameters that affect Velocity over hump

The possible factors that influenced the 85th percentile speed are noted. It is analyzed whether the length, breadth, average width over the hump has relation with the speed over the hump. Several correlation charts are shown below. The charts are made using the data below. The data below illustrates all the physical parameters along with the observed speed.

Table 4.3.1 Table for Hump Parameter

Hump stretch / **Places**	**Bishalchok**	**Yatayat**	**Jawlakhel**	**Satdobato**	**Buddhanagar**	**Chakupat**	**Jhamsikhel**	**Talchikhel**
L, m	6.11	3.1	5.911	6.1	5.81	4.61	5.6	4.5
L/W, m	4.766	9.118	12.826	5.083	10.741	11.5	16	5
A, sq.m	0.042	0.019	0.023	0.0664	0.021	0.02	0.019	0.043
A/W, m	0.033	0.056	0.05	0.055	0.038	0.05	0.054	0.047
W, m	1.281	0.34	0.46	1.2	0.54	0.4	0.35	0.9
H, m	0.049	0.084	0.075	0.083	0.057	0.075	0.081	0.071
H/W	0.038	0.247	0.163	0.069	0.106	0.188	0.231	0.079
Arc, m	1.286	0.389	0.491	1.215	0.556	0.435	0.395	0.914
Car observed speed, kmph	15	10	12	11.2	16	12.8	12	13.5
Bike observed speed, kmph	19	14.2	14.5	14	18	14	13.5	14.5

4.3.1 R-square value and equation of Velocity of Cars and Hump Parameter

Table 4.3.2 Table for R-square value and corresponding velocity equations for cars

	Function	R-square	Equation
A/W	Linear	0.84892	a/w=-0.00388v+0.09757
	Exponential	0.8103	a/w=0.14316e^(-0.086665v)
	Logarithmic	0.82732	a/w=-0.04933lnv+0.17317
	Polynomial	0.8470	a/w=0.00024v^2+0.00246v+0.05689
	Power	0.78546	a/w=0.76921v^(-1.099)
L	Linear	0.225	l=0.255v+1.935
	Exponential	0.254	l=2.365e^0.06
	Logarithmic	0.248	l=3.456lnv-3.567
	Polynomial	0.307	l=-0.082v^2+2.418v-11.94
	Power	0.254	l=0.641v^0.816
W	Linear	0.087	w=0.058v-0.061
	Exponential	0.132	w=0.164e^(0.100v)
	Logarithmic	0.092	w=0.766lnv-1.264
	Polynomial	0.101	w=-0.012v^2+0.379v-2.123
	Power	0.138	w=0.020v^1.325
Arc	Linear	0.047	arc=0.052v+0.038
	Exponential	0.11	arc=0.215e^(0.084v)
	Logarithmic	0.08	arc=0.691lnv-1.046
	Polynomial	0.09	arc=-0.011v^2+0.359v-1.933
	Power	0.116	arc=0.037v^(1.110)
H/W	Linear	0.366	h/w=-0.024v+0.448
	Exponential	0.316	h/w=1.319e^(-0.18v)
	Logarithmic	0.375	h/w=-0.31v+0.935
	Polynomial	0.381	h/w=0.002v^2-0.092v+0.884
	Power	0.32	h/w=57.68v^(-2.43)
L/W	Linear	0.026	l/w=-0.341v+13.75
	Exponential	0.028	l/w=14.34e^(-0.04v)
	Logarithmic	0.022	l/w=-4.09ln(v)+19.78
	Polynomial	0.037	l/w=0.122v^2+2.853v-6.749
	Power	0.026	l/w=31.09v^(-0.5)

From the above table, the best equation with maximum value of R-square is:

a/w=-0.00388v+0.09757. This is the linear function, where average height and speed are inversely proportional.

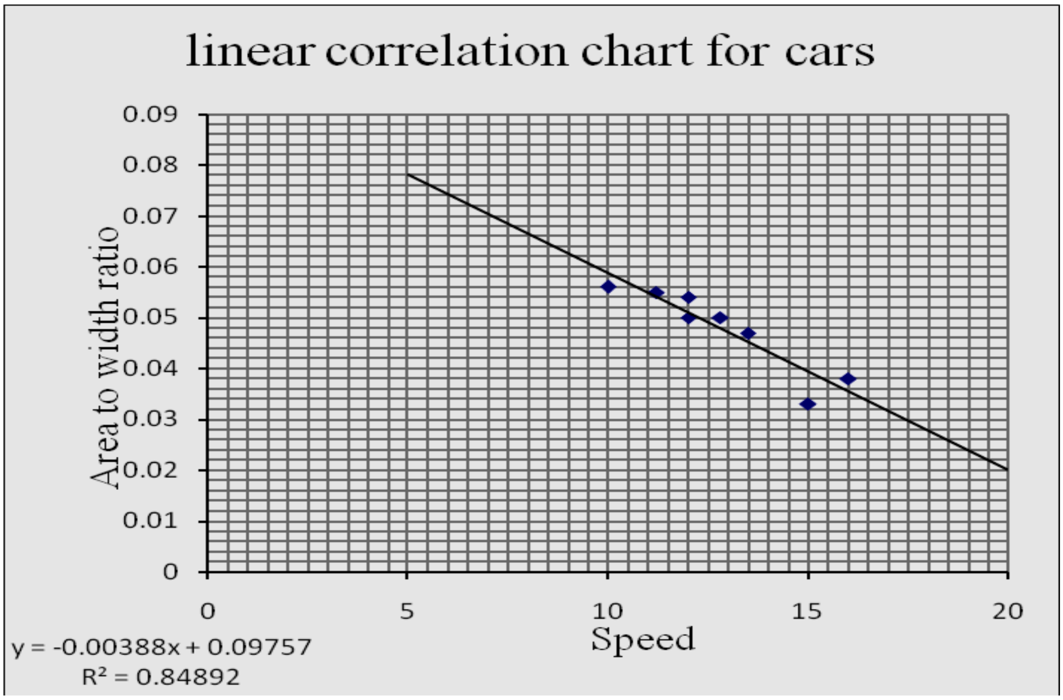

Figure 4.3.1 Linear correlation chart for cars

The percentage error between calculated and observed data for cars is shown below:

Table 4.3.3 Percentage error between calculated and normal data over hump

Places	Observed speed, kmph	Calculated speed, kmph	Percentage Error
Yatayat	10	10.71392	6.663459
Jawlakhel	12	12.26031	2.123187
Satdobato	11.2	10.97165	-2.08128
Buddhanagar	16	15.35309	-4.21353
Chakupat	12.8	12.26031	-4.40193
Jhamsikhel	12	11.22938	-6.86252
Talchikhel	13.5	13.03351	-3.5792
Bisalchowk	15	16.64175	9.865263

The maximum error is 9.8 percent. From the table above, it is seen that all the errors are within 10 percent.

4.3.2 R-square value and equation of Velocity of bikes and Hump Parameter

Table 4.3.4 Table for R-square value and corresponding velocity equations for bikes

	Function	R-square	Equation
A/W	Linear	0.90711	a/w=-0.00382v+0.10598
	Exponential	0.90322	a/w=0.1812v^(-0.08847v)
	Logarithmic	0.80213	a/w=-0.0618lnv+0.21563
	Polynomial	0.90612	a/w=-0.00005v^2-
	Power	0.890	a/w=2.286v^(-1.429)
L	Linear	0.16	l=0.205v+2.092
	Exponential	0.14	l=2.674(e^0.042v)
	Logarithmic	0.154	l=3.25ln(v)-3.633
	Polynomial	0.213	l=0.130(v^2)-4.059v+36.21
	Power	0.135	l=0.818v^(0.673)
W	Linear	0.198	w=0.083v-0.583
	Exponential	0.21	w=0.095e^(0.120v)
	Logarithmic	0.194	w=1.333lnv-2.936
	Polynomial	0.235	w=0.04v^2-1.220v+9.846
	Power	0.209	w=0.003v^(1.947)
Arc	Linear	0.187	arc=0.078v-0.478
	Exponential	0.196	arc=0.125e^(0.106v)
	Logarithmic	0.183	arc=1.249lnv-2.681
	Polynomial	0.23	arc=-0.041v^2-1.273v+10.33
	Power	0.194	arc=0.006v^(1.717)
H/W	Linear	0.013	h/w=0.003v+0.123
	Exponential	0.06	h/w=0.087e^0.066v)
	Logarithmic	0.043	h/w=0.023lnv+0.109
	Polynomial	0.068	h/w=-0.003v^2+0.037v+0.067
	Power	0.14	h/w=0.074v^(0.351)
L/W	Linear	0.126	l/w=-0.714v+20.24
	Exponential	0.115	l/w=28.07e^(-0.07v)
	Logarithmic	0.13	l/w=-11.7ln(v)+41.18
	Polynomial	0.142	l/w=0.276v^2-9.742v+92.48
	Power	0.116	l/w=271v^(-1.27)

From the table above, the best equation having maximum value of R-square is:

a/w=-0.00382v+0.10598. This is also the linear function where average height is inversely proportional to speed.

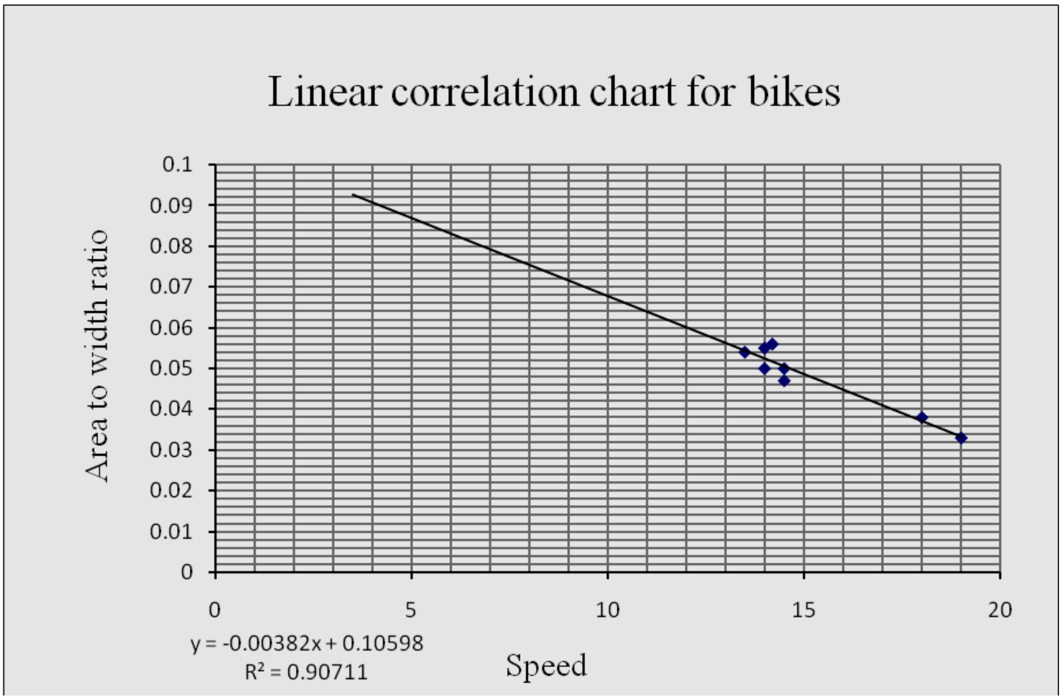

Figure 4.3.2 Linear correlation chart for bikes

Table 4.3.5 Percentage error of speed for bikes over the hump

Places	Observed speed, kmph	Calculated speed, kmph	Percentage Error
Bisalchowk	19	19.10471	0.548095
Yatayat	14.2	13.08377	-8.53141
Jawlakhel	14.5	14.65445	1.053948
Satdobato	14	13.34555	-4.90388
Buddhanagar	18	17.79581	-1.1474
Chakupat	14	14.65445	4.465881
Jhamsikhel	13.5	13.60733	0.788765
Talchikhel	14.5	15.43979	6.086809

The maximum percentage error is found to be 8.5 percent. Here, all errors are within 10 percent range.

4.4 Analysis of Reduction of Speed over Hump

The analysis of reduction of speed over hump is done with the help of the calculations done using the data obtained from the table below

Table 4.4.1 Comparison of speed between normal and hump section

Places		Bishalchok	Yatayat	Jawlakhel	Satdobato	Buddhanagar	Chakupat	Jhamsikhel	Talchikhel
Cars observed speed, Kmph	v85 hump,kmph	15	10	12	11.2	16	12.8	12	13.5
	v85 normal,kmph	32	16	19.5	16.5	32	23.5	19	28.5
Bikes observed speed, Kmph	v85 hump,kmph	19	14.2	14.5	14	18	14	13.5	14.5
	v85 normal,kmph	33	19	28	17.2	33	30	17.5	31
Cars calculated speed,	V85 hump,kmph	16.642	10.714	12.26	10.972	15.353	12.26	11.229	13.034
Bikes calculated speed,	V85 hump,kmph	19.105	13.083	14.654	13.346	17.796	14.654	13.607	15.439

Similarly, the calculated normal speeds for bikes and cars are 27.744 kmph and 25.147 kmph respectively(putting A/W=O in the equations). Hence:

The average percent reduction of observed speed at hump for bikes is

=[(33-19)/33+(19-14.2)/19+(28-14.5)/28+(17.2-14)/17.2+(33-18)/33+(30-14)/30+(17.5-13.5)/17.5+(31-14.5)/31]/8=38.663%

The average percent reduction of calculated speed at hump for bikes is

=[(27.744-19.105)/27.444+(27.744-13.084)/27.444+(27.744-14.654)/27.444+(27.744-13.346)/27.444+(27.744-17.796)/27.444+(27.744-14.654)/27.444+(27.744-13.607)/27.444+(27.744-15.439)/27.444]/8=45.1%

The average percent reduction of observed speed at hump for cars is:

=[(32-15)/32+(16-10)/16+(19.5-12)/19.5+(16.5-11.2)/16.5+(32-16)/32+(23.5-12.8)/23.5+(19-12)/19+(28.5-13.5)/28.5]/8=43.275%

The average percent reduction of calculated speed at hump for cars is

=[(25.147-16.642)/25.147+(25.147-10.714)/25.147+(25.147-12.260)/25.147+(25.147-10.972)/25.147+(25.147-15.343)/25.147+(25.147-12.260)/25.147+(25.147-11.229)/25.147+(25.147-13.034)/25.147]/8=49.075%

With the help of above calculations, a table is constructed as shown below:

Table 4.4.2 Observed and calculated percentage reduction of speed at hump

	Observed percent speed reduction at hump	Calculated percent reduction at hump	Error
Cars	43.28%	49.08%	5.80%
Bikes	38.66%	45.10%	6.44%

4.5 Comparison of Speeds of Bikes and Cars

The speed of bikes is generally more than that of cars at every location, whether it may be normal section, or hump section. The percent by which observed speed of cars is less than that of bikes at normal section is

=[(33-32)/33+(19-16)/19+(28-19.5)/28+(17.2-16.5)/17.2+(33-32)/33+(30-23.5)/30+(17.5-19)/17.5+(31-28.5)/31]/8

=9.675%

The percent by which the calculated speed of cars is less than that of bikes at normal section is= (27.744-25.147)/25.147*100=9.373%

The percent by which the observed speed of cars is less than that of bikes at hump section is

=[(19-15)/19+(14.2-10)/14.2+(14.5-12)/14.5+(14-11.2)/14+(18-16)/18+(14-12.8)/14+(13.5-12)/13.5+(14.5-13.5)/14.5]/8

=15.68%

The percent by which the calculated speed of cars is less than that of bikes at hump section is

=[(19.105-16.642)/19.105+(13.088-10.714)/13.083+(14.654-12.260)/14.5+(13.346-10.972)/13.346+(17.796-15.353)/17.796+(14.654-12.260)/14.654+(13.607-11.229)/13.607+(15.439-13.034)/15.439]/8=16.063%

With the help of above calculations, a table is constructed as shown below:

Table 4.5 Observed and calculated percent reduction of speed of cars with respect to bikes

	Observed Percent reduction of speed of cars with respect to bikes	Calculated Percent reduction of speed of cars with respect to bikes	Error
Normal section	9.68%	9.37%	0.30%
Hump section	15.68%	16.06%	0.38%

4.6 Analysis of maximum and minimum speeds

Table 4.6 Table for minimum speed over hump and maximum speed in normal section

	Minimum calculated speed(A/W=0.06), kmph	Maximum calculated speed(A/W=0), kmph	Observed average normal speed, kmph	NRS maximum speed criteria, kmph
Bikes	12.02	27.744	26.0875	<30
Cars	9.68	25.147	23.375	<30

As shown above in table, the minimum calculated speed (putting average height=0.06 m) for bikes and cars are found to be 12.02 kmph and 9.68 kmph respectively. Similarly the maximum calculated speed is found to be 27.74 kmph and 25.147 kmph for bikes and cars respectively. The observed average normal speed are found to be 26.08 kmph and 23.375 kmph for bikes and cars respectively, which comply with the NRS standard.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

One of the major things known from this thesis is that the geometry of humps at every place is different. Hence, the conclusion is that proper geometry must be designed to prevent crashes. Proper design may be planned using the linear equations obtained. The equations relate the average height and speed.

For cars, the standard equation is: $a/w=-0.00388v+0.09757$

For bikes, the standard equation is: $a/w=-0.00382v+0.10598$

No statically significant relationship could be obtained between speed and length of hump. Likewise, the safe speed of vehicles over the hump doesn't have relation with width. As stated by Sahoo and Fwa, there is no correlation between speed and height to width ratio of hump. There is no any correlation between speed and arc length, and speed and cross-sectional area of Hump. Hence in case of Kathmandu valley, only area to width is the significant for controlling speed, and vice versa.

The speed of bikes is greater than that of cars on the minor roads of Nepal. At normal section, the observed speed of cars is less than that of bikes by 9.675%. The calculated speed of cars is less than that of bikes by 9.373%, thus giving 0.302 % error. In hump section, the observed speed of cars is less than that of bikes by 15.68%. Likewise the calculated speed of cars is less than that of bikes by 16.063%, giving 0.383% error.

In hump section, the speed reduction is large for cars. The average observed percent reduction of speed at hump for cars is 43.275%. The calculated percent speed reduction is 49.075, giving an error of 5.8% between the two. Similar is the case for bikes. The observed average percent reduction of speed at hump for bikes is 38 percent. The calculated percent speed reduction is 45.1%, giving an error of 6.437%. This concludes that the speed hump's primary function is to control the speed, and hence reduce the crashes.

The observed minimum speeds are 9.68 kmph and 12.02 kmph for cars and bikes respectively. The observed average normal speed of cars and bikes are 23.375

kmph and 26.0875 kmph respectively. These values comply with the Nepal Road standard criteria, which states the maximum speed of vehicles where hump is provided should be less than 30 kmph.

Overall, based on the field experiments on hump geometry and hump crossing speeds of bikes and cars, this investigation shows that statically significant regression relationships could be established between hump-crossing speed and hump geometry characterized by area to width ratio. The relationships provide a useful tool for field engineers to design hump geometry for speed control. Hence the recommendation is that the hump should be designed using the equation as suggested above, for the safe and orderly movement of traffic.

REFERENCES

Sahoo, P., 2010, “Geometric design of speed control humps in Bhubaneswor city”, MSC Thesis, Department of Civil Engineering, College of Engineering and Technology , Bhubaneswar, Odisha.

Bunte, L., 2000, “Traffic Calming Programs & Emergency Response: A competition of two public goods”, *Professional Report Presented to the Faculty of the Graduate School of the University of Texas at Austin*.

Vrubel, Y., Kapskij, D., Mazalevskij, D., Samoylovich, T., Korzhova, T, Kuzmenko, V., 2008, “Some questions of speed humps application”, *Report on Reliability and Statistics in Transportation and Communication.*

IRC: 99-1988, “Tentative guidelines on the provision of speed breakers for control of vehicular speeds on minor roads”, 1996.

<URL:https://law.resource.org/pub/in/bis/irc/irc.gov.in.099.1988.pdf >

Nepal Road Standard 2070, July 2016.

Shalom, H., 2004, “Economic evaluation of road safety measures”, *Report on the framework, testing and future needs.*

Jain, M., Singh, A., 2013, “Speed-Breaker Early Warning System”, *Report on causes of failure of roads.*

Hamsa, N.,Kadar,Y., “The Effect of Road Hump in Reducing Speed of Motorcars in a Residential Area in Kuala Lumpur”, *Journal of Design and Built Environment.*

Philip, W., 1998, “Towards A Canadian Standard for the Geometric Design of Speed Bumps”, MSC Thesis, Carleton University Ottawa, Ontario, Canada.

APPENDICES

APPENDIX A – DATA SHEETS

APPENDIX B- PHOTOGRAPHS

APPENDIX A: DATA SHEETS

Table 1 Sample of data extraction of cars at normal section (at Jhamsikhel)

1	1:17	1:20	3.00	12.00
2	1:18	1:20	2.00	18.00
3	2:01	2:03	2.00	18.00
4	3:21	3:24	3.00	12.00
5	4:43	4:46	3.00	12.00
6	5:43	5:46	3.00	12.00
7	6:50	6:52	2.00	12.00
8	7:10	7:12	2.00	18.00
9	7:33	7:35	2.00	12.00
10	9:01	9:03	2.00	18.00
11	9:10	9:11	1.00	12.00
12	10:15	10:17	2.00	12.00
13	11:13	11:15	2.00	18.00
14	12:53	12:55	2.00	18.00
15	13:33	13:35	2.00	12.00
16	14:28	14:30	2.00	18.00
17	15:11	15:12	1.00	36.00
18	15:21	15:22	1.00	12.00
19	16:11	16:14	3.00	36.00
20	17:21	17:23	2.00	12.00
21	18:40	18:42	2.00	18.00
22	19:56	19:58	2.00	18.00
23	20:03	20:05	2.00	18.00
24	21:11	21:13	2.00	18.00
25	22:12	22:14	2.00	36.00
26	22:51	22:53	2.00	18.00
27	0:11	0:14	3.00	12.00
28	1:11	1:13	2.00	18.00
29	2:03	2:06	3.00	12.00

30	3:05	3:07	2.00	18.00
31	4:06	4:08	2.00	18.00
32	5:06	5:08	2.00	36.00
33	6:11	6:13	2.00	18.00
34	7:53	7:59	6.00	6.00
35	8:15	8:18	3.00	12.00
36	8:05	8:08	3.00	12.00
37	9:21	9:23	2.00	12.00
38	10:53	10:55	2.00	18.00
39	11:02	11:04	2.00	18.00
40	12:11	12:13	2.00	18.00
41	12:37	12:38	1.00	36.00
42	12:45	12:46	1.00	36.00
43	13:33	13:36	3.00	12.00
44	14:16	14:18	2.00	12.00
45	15:13	15:15	2.00	18.00
46	16:12	16:14	2.00	18.00
47	17:13	17:15	2.00	36.00

Table 2 85th percentile speed calculation process(Jhamsikhel)

Ci	mid value	bin array	Frequency	Cf	% cf
4 to 8	6	7.99	2	2	1.098901
8 to 12	10	11.99	3	5	2.747253
12 to 16	14	15.99	61	66	36.26374
16 to 20	18	19.99	84	150	82.41758
>36	38		32	182	100

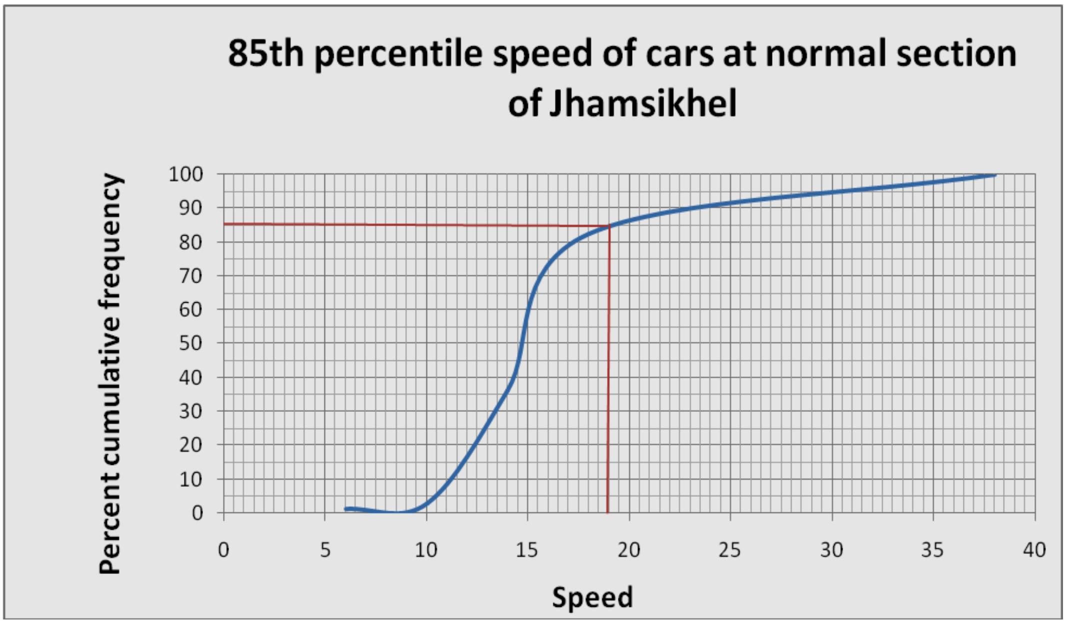

Figure 1 figure showing 85th percentile speed (Jhamsikhel)

Table 3 Sample of data extraction of bikes at hump section (of Jawlakhel)

s.no.	Time of entry	Time of exit	time taken	Time	velocity(kmph)
1	0:08	0:10	0:02	2	18
2	0:13	0:17	0:04	4	9
3	0:14	0:19	0:05	5	7.2
4	0:15	0:19	0:04	4	9
5	0:22	0:25	0:03	3	12
6	0:34	0:38	0:04	4	9
7	0:39	0:42	0:03	3	12
8	0:59	1:02	0:03	3	12
9	1:23	1:27	0:04	4	9
10	1:36	1:42	0:06	6	6
11	1:39	1:44	0:05	5	7.2
12	1:45	1:48	0:03	3	12
13	1:47	1:49	0:02	2	18
14	1:51	1:57	0:06	6	6
15	2:07	2:09	0:02	2	18

16	2:14	2:18	0:04	4	9
17	2:15	2:18	0:03	3	12
18	2:22	2:24	0:02	2	18
19	3:04	3:08	0:04	4	9
20	3:06	3:09	0:03	3	12
21	3:12	3:16	0:04	4	9
22	3:13	3:17	0:04	4	9
23	3:15	3:19	0:04	4	9
24	3:27	3:29	0:02	2	18
25	3:29	3:33	0:04	4	9
26	3:35	3:39	0:04	4	9
27	3:39	3:41	0:02	2	18
28	3:42	3:46	0:04	4	9
29	3:45	3:48	0:03	3	12
30	3:48	3:53	0:05	5	7.2
31	4:09	4:11	0:02	2	18
32	4:12	4:14	0:02	2	18
33	4:20	4:23	0:03	3	12
34	4:27	4:30	0:03	3	12
35	4:37	4:42	0:05	5	7.2
36	5:04	5:08	0:04	4	9
37	5:06	5:10	0:04	4	9
38	5:10	5:13	0:03	3	12
39	5:14	5:18	0:04	4	9
40	5:19	5:22	0:03	3	12
41	5:21	5:24	0:03	3	12
42	5:30	5:32	0:02	2	18
43	5:34	5:39	0:05	5	7.2
44	5:47	5:50	0:03	3	12
45	6:18	6:21	0:03	3	12
46	6:30	6:34	0:04	4	9
47	6:32	6:34	0:02	2	18

Table 4 85th percentile speed calculation process (Jawlakhel)

CI	mid value	%cf	bin array	Frequency	Cf
4 to 8	6	12.2549	7.99	50	50
8 to 12	10	49.7549	11.99	153	203
12 to 16	14	82.59804	15.99	134	337
16 to 20	18	98.03922	19.99	63	400
36 to 40	38	100		8	408

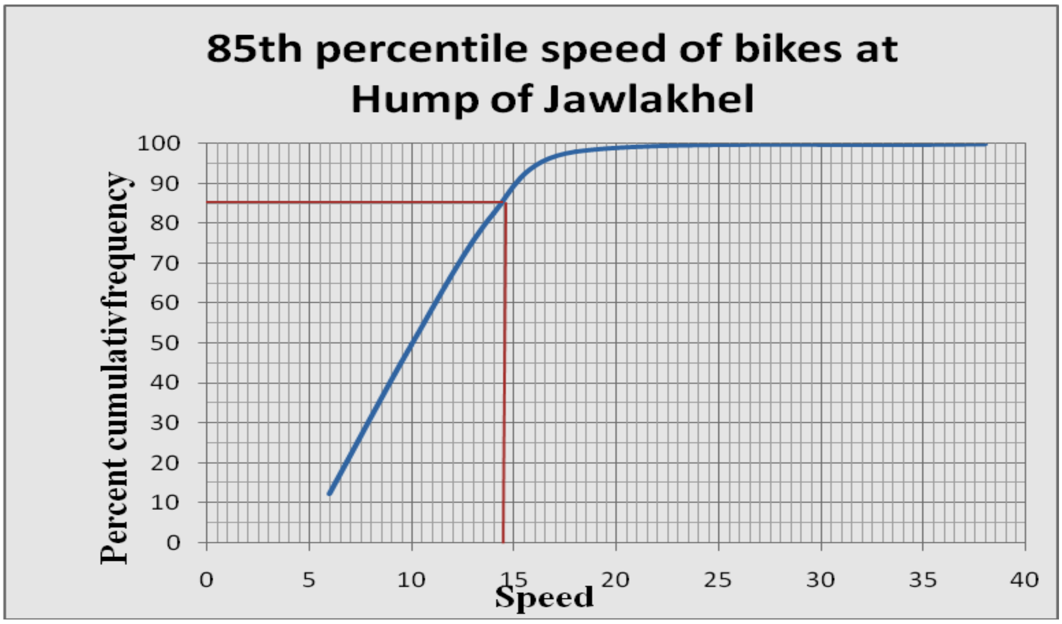

Figure 2 figure showing 85th percentile speed (Jawlakhel)

APPENDIX B: PHOTOGRAPHS

Figure 1 Picture at hump section of Satdobato

Figure 2 Picture at hump section of Buddhanagar site

Figure 3 Picture at hump section of Jhamsikhel site

Figure 4 Picture at hump section of Talchikhel site

Figure 5 Picture at hump section of Chakupat site

Figure 6 Picture at hump section of Jawlakhel site

Figure 7 Picture at hump section of Bishalchowk site

Figure 8 Picture at hump section of Yatayat site

Figure 9 Picture at normal section of Satdobato

Figure 10 Pictkure at normal stretch of Jhamsikhel

Figure 11 Picture at normal stretch of Talchikhel

Figure 12 Picture at normal stretch of Chakupat

Figure 13 Picture at normal stretch of Jawlakhel

Figure 14 Picture at normal section of Bishalchok

Figure 15 Picture at normal section of Buddhanagar

Figure 16 Picture at normal section of Yatayat