Computation of Particulate Emission Load from Vehicular Traffic on Road Network

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ABSTRACT

The present study on traffic volume monitoring aims to compute total particulate emission load from urban road vehicular traffic and to find average emission factor. An industrial area Pandesara was selected as study area for its commercial and industrial activity, the contribution of public and private vehicle emissions in this area were high. Vehicle emissions include tailpipe emissions and road dust resuspensions. Tailpipe emission was the highest in off-road vehicles even their traffic volume was the least of all. Road dust resuspension due to vehicular speed was highest in 2 wheelers. Road dust resuspension concentrations due to silt fraction was found to be maximum in heavy motor vehicles. Total particulate matters concentrations emitted from vehicles and average emission factor were found to be 251616 gm/hr and 0.79 gm/Veh/Km respectively for entire Pandesara zone. Road dust resuspension plays a significant role in vehicular emission, still having less awareness among people worldwide.

Keywords:

Particulate Matter, Tailpipe Emission, Traffic Volume, Speed, Road Dust Resuspension, Turbulent Wake Height

1. INTRODUCTION

Urbanization has brought unprecedented growth in business, real estate, construction activities of roads and buildings, transportation and industries to accommodate the migrating population. It also serves as the most critical part of economy and provides employment to a large-scale population of skilled and unskilled workforce. In cities, major contributors of atmospheric pollutants are vehicular emissions, industries, open burning, mining, construction and demolition activities, open burning, street hawkers and eateries. Steady growth in vehicular population has put environmental stress on urban centres in various forms particularly causing poor air quality. Road transport is a significant source of air pollution, especially in urban areas. The air quality, especially in heavily populated cities, is strongly affected by road transport emissions

1.1 Motivation of the present study:

Contribution to air pollution from road transport sector emissions is higher than national average in India (*NITI Aayog, India*). Only a few studies (*Nagendra, Alshetty et al., 2022*) regarding transport sector emissions have been conducted in India. The present study area is categorized under industrial areas and heavy traffic zones. That is why silt-loading rate is higher. Road dust resuspension concentration occurs much more than tailpipe emissions, but awareness is low among people. The lack of research and awareness among people regarding road dust resuspension in affecting the air quality compared to tailpipe emissions, serves as impetus to conduct the study. Transport sector helps in minimizing time, increase in production rate and profit. Majority of the households have a minimum of four vehicles for their conveyance. So, the contribution of pollutants emitted from the transport sector releasing into the atmosphere cannot be ignored. After computation of pollutant loads from vehicles, useful solutions for mitigation measures of ambient air pollution can be thought.

1.2 Objectives:

i. To estimate total pollutants emission (gm/hr) emitted from vehicles on entire road network

ii. To determine the average emission factor on entire road networks due to both exhaust emissions (gm/Veh/Km) and road dust resuspension (gm/Veh/Km)

1.3 Scope:

Tailpipe emission test was not directly conducted for every vehicle, instead the emission control limit with 10% excess was used due to increase in tailpipe emission owing to congestion flow and gradient of terrain. To determine silt loading rate, there should have been usage of air blower and vacuum cleaner followed by 75μ sieve analysis road dust particles, instead silt loading rate (gm/m^2/day) was derived from many literatures based upon various specific conditions. Real time traffic volume monitoring was done manually through video recording instead of using satellite imagery software or any traffic data extractor software or any device.

2. STUDY METHODOLOGY

2.1 Site description:

Surat, a metropolitan diamond city of India lies in southern part of Gujrat. The Pandesara zone has area of 4.41 km^2 and population about 63,812 in the year 2020 among thirty-seven traffic zones of Surat. It hosts more than 230 industries and pays homage to 1,50,000 residents at present. Transportation of vehicles are continuously going on for personal, public, commercial, and industrial purposes on road network of GIDC, Pandesara.

There are about thirty-seven traffic zones in Surat. Pandesara GIDC zone is one among them having area of 4.41 Km^2. It bears transportation of all category's vehicles such as two wheelers, three wheelers, four wheelers, light motor vehicles, heavy motor vehicles and off-road vehicles. They are being used for personal, public, commercial and industrial purposes. Required data are traffic volume (vehicles/hour), road-dust samples from both paved and unpaved roads, open-source GIS and other traffic related parameters. Pandesara road network shown in *fig. 2.1* contains forty-one road stretches, a number of nodes and connectors among which there are twenty-nine collector roads shown in *fig. 2.3* and twelve arterial roads shown in *fig. 2.4*. Categorisation of roads is based upon length of road stretch. Each stretch contains a number of lanes, road types and hierarchy, width, length, free-flow speed, direction and allowed transport system.

Fig 2.1 Pandesara Road Network

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2.2 Traffic count:

Traffic volume is defined as number of vehicles crossing a particular cross-section on any road stretch per unit period of time. Monitoring was done in mid-block road, neither at any inter junction nor in any highway having more than four lanes. For academic purpose, traffic volume monitoring was conducted in two-lane-two-way, three-lane-two-way and four-lane-two-way road. There was no use of passenger car units (PCU) concept since ambient air pollutants concentration due to vehicular stream is totally independent of this. Traffic volume monitoring for each road stretch was conducted for 20 minutes. In order to find out the total particulate emission (gm/hr), it was multiplied with ‘3’ and the length of respective road stretch. Categorisation of vehicles into 2 wheelers, 3 wheelers, 4 wheelers, light motor vehicles, heavy motor vehicles and off-road vehicles (Tractors, rollers and JCB) is based upon number of wheels, seating capacity, dimensions of vehicle, mileage, engine displacement volume(cc) and quantum of work load.

2.3 Data collection and Interpretation:

As shown in *fig 2.2*, real time traffic volume monitoring was necessary. Input parameters were length of each road stretch, width of both paved and unpaved roads, traffic volume, silt loading rate on road surface, weight and height of every individual vehicle and free flow speed of traffic stream. During traffic volume monitoring, the number plate of every category of vehicle was continuously noted from video recording because it gave details of the owners as well as vehicles including fuel type, technology norms, engine displacement (cc), kerb weight, height using R.T.O.’s official website. Instantaneous speed of each vehicle of every road stretch was noted using sensor-based doppler radar gun which works on the principle of doppler effect. The data of road width were necessary in order to know the number of lanes of road and expected range of traffic capacity.

Fig 2.2 Traffic Volume Monitoring at BSNL tower chowk, Pandesara

		Collector Roads				
Sr. No.	Road type	Length (Km)	Width (m)			Number of lanes
			Carriage-way	Shoulder/Parking	divider	
Road A	Concrete	0.24	4.85	2.85	undivided	2-lane-2-way
Road B	Bituminous	0.24	5.85	2.85	undivided	2-lane-2-way
Road C	Bituminous	0.24	14.28	4.15	undivided	4-lane-2-way
Road D	Bituminous	0.24	14.2	5.3	undivided	4-lane-2-way
Road E	Bituminous	0.24	14.3	5.3	undivided	4-lane-2-way
Road F	Concrete	0.20	14.3	5.3	undivided	4-lane-2-way
Road G	Concrete	0.32	14.3	5.3	undivided	4-lane-2-way
Road H	Concrete	0.24	14	2.5	undivided	4-lane-2-way
Road I	Bituminous	0.24	14.1	3.3	undivided	4-lane-2-way
Road J	Bituminous	0.24	14.3	4.25	undivided	4-lane-2-way
Road K	Bituminous	0.35	9.43	No shoulder	1.15 m	3-lane-2-way
Road L	Bituminous	0.36	14.3	2.44 & 1.75	undivided	4-lane-2-way
Road M	Bituminous	0.24	11.7	4.85	undivided	4-lane-2-way
Road N	Concrete	0.20	9.9	3.5	undivided	3-lane-2-way
Road P	Concrete	0.33	9.7	3.5	undivided	3-lane-2-way
Road Q	Bituminous	0.19	14.3	3.5	undivided	4-lane-2-way
Road R	Bituminous	0.32	7.3	3.5	undivided	2-lane-2-way
Road S	Bituminous	0.22	7.3	3.5	undivided	2-lane-2-way
Road T	Bituminous	0.20	9.1	3.5	undivided	3-lane-2-way
Road U	Bituminous	0.32	14	3.4	undivided	4-lane-2-way
Road V	Bituminous	0.22	7.9	4	undivided	2-lane-2-way
Road W	Bituminous	0.48	7.75	3.17	undivided	2-lane-2-way
Road Y	Bituminous	0.29	6.5	3.0 & 2.8	undivided	2-lane-2-way
Road Z	Concrete	0.29	9.5	3.6	undivided	3-lane-2-way
A	Bituminous	0.37	7.3	4.7	undivided	2-lane-2-way
B	Concrete	0.21	9.38	3.13	undivided	4-lane-2-way
G	Bituminous	0.21	6.25	2.63 & 2.7	undivided	2-lane-2-way
Y	Bituminous	0.30	14	4.2	undivided	4-lane-2-way
F	Concrete	0.24	7.9	2.1	undivided	2-lane-2-way

Table 2.1 shows details about all collector roads such as whether their pavement is concrete or bituminous, dimensions such as length of each road stretch, width, dividers and lanes

Table 2.1 **Details of dimensions of Collector Roads**

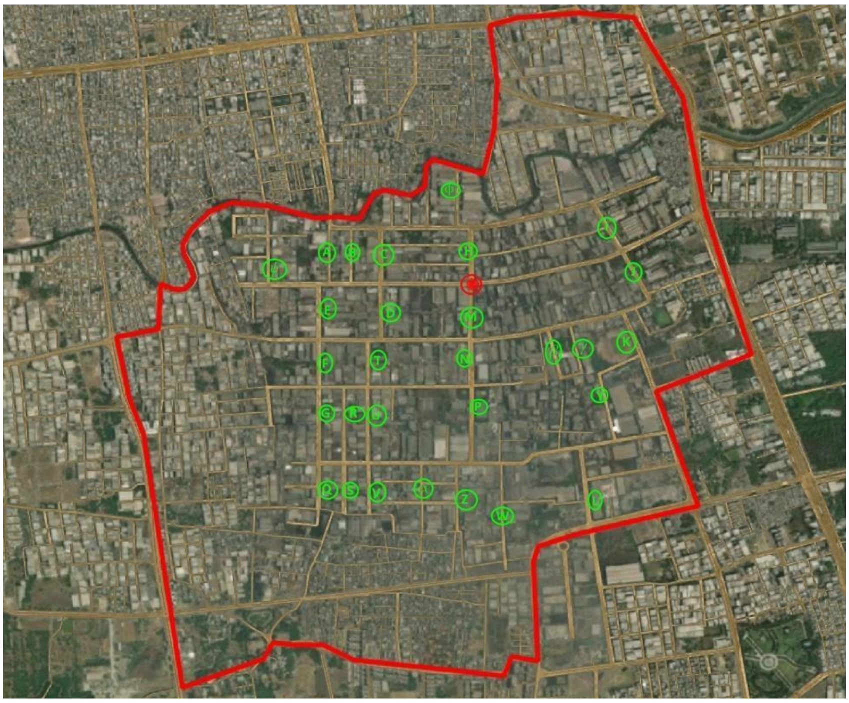

Fig 2.3 Collector Roads of Pandesara, GIDC

Table 2.2 shows details of all arterial roads such as whether their pavement is concrete or bituminous, dimensions such as length of each road stretch, width, dividers and lanes

Table 2.2 **Details of dimensions of Arterial Roads**

		Arterial Roads				
Sr. No.	Road type	Length(Km)	Width (m)			Number of lanes
			Carriage-way	Shoulder/Parking	Divider(m)	
Road 1	Concrete	0.56	7.2	3.1	1.1	2-lane-1-way
Road 2	Concrete	0.49	7	4.5	1	2-lane-1-way
Road 3	Bituminous	0.60	6.7	3.58	0.6	2-lane-1-way
Road 4	Bituminous	0.61	7.3	4.57	0.9	2-lane-1-way
Road 5	Bituminous	0.64	12.2	4.05	undivided	4-lane-2-way
Road 6	Concrete	0.60	7.2	4.65	1	2-lane-1-way
Road 7	Concrete	0.73	7.2	4.8	1.05	2-lane-1-way
Road 8	Bituminous	0.60	9.3	3.6	undivided	3-lane-2-way
Road 9	Bituminous	0.60	7.5	4.5	1	2-lane-1-way
Road10	Bituminous	0.79	7.7	5 & 2.5	undivided	2-lane-2-way
Road11	Bituminous	1.44	6.1	3.5	undivided	2-lane-2-way
Road12	Bituminous	0.37	5	1	undivided	2-lane-2-way

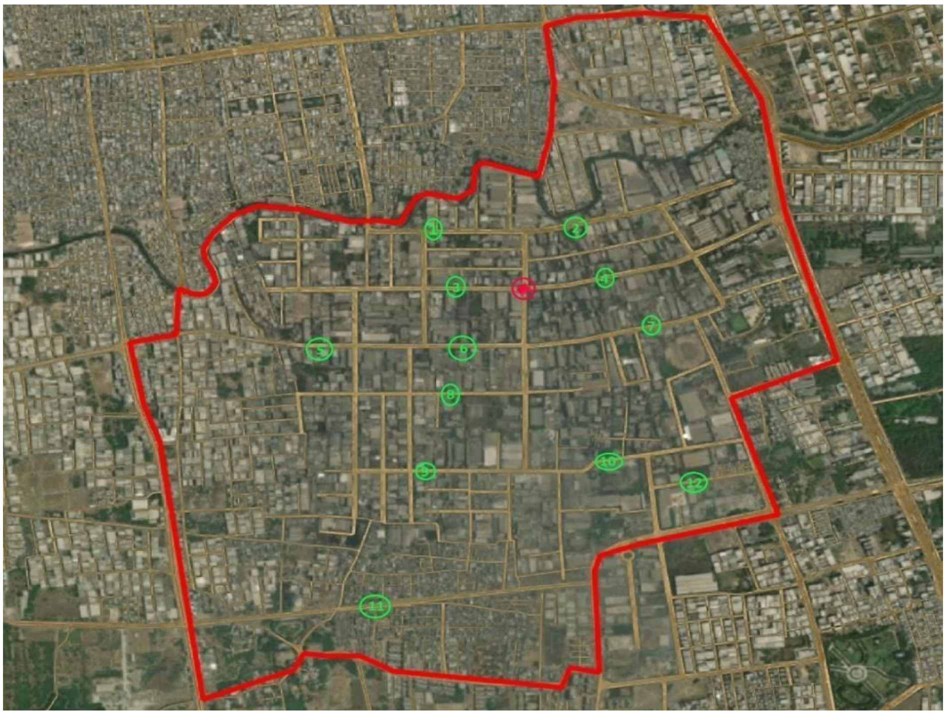

Fig 2.4 Arterial Roads of Pandesara, GIDC

Table 2.3 **Traffic Characteristics of Pandesara Road Network**

	Traffic Volume (Veh/hr)		Speed (Km/hr)		
Road	Peak hour	Non-Peak hour	Mean (all)	Maximum	Vehicle of maximum speed
Road-1	1548	225	38	52	4W
Road-2	705	42	26	55	4W
Road-3	624	87	29	50	2W
Road-4	1569	150	24	58	4W
Road-5	1392	120	21	50	4W
Road-6	888	156	23	45	2W
Road-7	1341	192	20	50	4W
Road-8	264	33	19	46	2W
Road-9	738	87	18	48	4W
Road-10	255	27	17	50	2W
Road-11	627	90	16	45	4W
Road-12	54	12	23	30	ORV
Road-A	1035	126	24	50	2W
Road-B	102	24	26	29	2W
Road-C	561	66	28	45	2W
Road-D	471	51	27	55	2W
Road-E	1095	57	29	49	2W
Road-F	663	51	24	53	2W
Road-G	414	63	26	55	4W
Road-H	966	129	27	50	4W
Road-I	738	72	23	52	4W
Road-J	981	63	22	48	4W
Road-K	1098	63	22	50	2W
Road-L	204	24	58	111	4W

Road-M	1098	156	20	43	2W
Road-N	981	141	38	51	4W
Road-P	774	72	36	50	2W
Road-Q	312	42	35	55	4W
Road-R	96	12	32	49	2W
Road-S	222	27	39	47	2W
Road-T	285	42	34	34	2W
Road-U	273	42	30	49	4W
Road-V	228	33	32	55	2W
Road-W	306	48	31	34	4W
Road-Y	36	12	21	41	HMV
Road-Z	246	33	20	51	4W
a	348	42	19	37	4W
b	126	15	18	35	2W
g	60	8	17	38	2W
y	447	51	16	52	4W
F	159	27	15	48	2W

2.4 Estimation of pollutants concentrations due to transport sector:

Emissions from vehicular transportations is categorized into two types:

i. Exhaust Emission
ii. Non-Exhaust Emission

Exhaust emission is due to burning of fuels whereas non-exhaust emission (road dust resuspension) is due to silt loading rate on roads either being paved or unpaved and free flow speed of vehicular stream. Exhaust emission is again divided into two types i.e., hot exhaust emission and cold start exhaust emission, whereas cold-start exhaust emission is negligible.

2.4.1 Exhaust Emission:

Since tailpipe emission test was not directly conducted for each vehicle, emission control limit with 10% excess value was used. Emission control limit was easily derived from portals of CPCB, ARAI (Bharat Stage norms) and European emission standards (Euro norms), required data were fuel type, technology norms, engine displacement volume(cc) and vehicles' category (2 wheelers, 3 wheelers, 4 wheelers, light motor vehicles, heavy motor vehicles and off-road vehicles) as shown in *table 2.4*. Light motor vehicles include mini goods carriers having kerb weight less than or equal to 3500 kg and heavy motor vehicles include buses and trucks having kerb weight greater than 3500 kg (*Alshetty et al., 2020*). The traffic volume monitoring was used to calculate the hourly emissions for the entire Pandesara region of Surat city for a given period of time. In general, the hourly hot exhaust emissions of particulate matter (PM) produced by a road stretch j that has length L, in which 'n' vehicles circulate with an average speed (v), are calculated using the equation (2.1) (*Samaras, Tsegas et al.,2012*) :

$$\text{Emissions}(i,j) = \sum [\, L_j \times n_j \times P_{category\,(i)} \times P_{technology\,(i)} \times EF_{Category} \,] \quad (2.1)$$

Emissions (i,j) = Hourly hot exhaust emissions of particulate matter (PM) produced by n vehicles that circulate on the stretch j (gm/hr)

$\sum$ = Summation of emissions of each road stretch with their respective parameters

L = Length of each road stretch (Km)

n = Traffic Volume on the road stretch j at the particular hour (Veh/hr)

$P_{category}$ = Percentage of vehicles per vehicle category (motorcycles, auto-rickshaw, passenger cars, light motor vehicles, heavy motor vehicles and buses, off-road vehicles)

$P_{technology}$ = Percentage of vehicles per technology (Bharat Stage norms) (BS-I, BS-II, BS-III, BS-IV, BS-VI)

$EF_{cateogory}$ (v) = Emission factor per category for average speed (v) (gm/Veh/Km)

A case study of non-peak hour of road-10 is shown in *table 2.4* below

Table 2.4 **Engine details and corresponding emission control limit (vehicles)**

		2W			Tailpipe Emission			10% excess
State Code		Series	Fuel Type	Engine	CC	gm/Km/Veh	gm/Km	gm/Km
	GJ 05	SJ	Petrol	BS-IV	113.2	0.028	0.028	0.031
		FY	Petrol	BS-VI	109.51	0.05	0.05	0.055
		EV	Electric	N/A	N/A	0	0	0
		PS	Petrol	BS-IV	125	0.028	0.028	0.031
		FV 5691	Petrol	BS-VI	162.7	0.05	0.05	0.055
	GJ 27	CK	Petrol	BS-IV	109.2	0.028	0.028	0.031
		3W						
State Code		Series						
	GJ 05	CT	CNG	BS-IV	236.2	0.118	0.118	0.13
		4W						
State Code		Series						
	GJ 05	RQ	Petrol	BS-VI	1199	0.0045	0.0045	0.005
		LMV						
State Code		Series						
	GJ 05	AT 1889	Diesel	BS-III	5195	0.475	0.475	0.52
		HMV						
State Code		Series						
	GJ 05	AT 2860*2	Diesel	BS-IV	5883	0.071	0.142	0.16
		ORV						
State Code		Series						
	GJ 05	CE 6711	Diesel	BS-III	4500	1.09	1.09	1.20
	GJ 05	X 2871*3	Diesel	BS-IV	2730	1.09	3.27	3.60

(*Source* : ARAI, CPCB, MoEFCC)

2.4.2 Road dust resuspension due to silt loading rate on road surface:

Road dust resuspension in the form of $PM_{2.5}$ and PM_{10} due to traction of vehicle tyres with dust particles on road surface (either paved or unpaved) can be calculated using empirical formula from USEPA as represented in equation (2.2) (*Nagendra, Alshetty et al., 2022*)

$$E = k * (sL)^{0.91} * (W)^{1.02} \quad (2.2)$$

where,

E : particulate emission (gm/Veh/Km)

K : particle size multiplier (gm/Veh/Km)

: 0.15 gm/Veh/Km for $PM_{2.5}$ and 0.62 gm/Veh/Km for PM_{10}

sL : road surface silt loading (g/m^2)

W : average weight (tons) of the vehicles travelling the road.

Silt loading rate ($gm/m^2/day$) on paved surface depends upon seasonal variation (*Bhaskar, Sharma et al., 2008*), vehicular density per hour and speed (*Nagendra, Alshetty et al., 2022*), phase of construction (*Nagendra, Alshetty et al., 2022*), presence of near about industries or domiciles (*Nagendra, Alshetty et al., 2022*), types of road (branch road/arterials/outer ring/expressway) (*Zhang, Wang et al.,2017*), types of road surface (*Kumar, Gulia, Goyal et al., 2018*), dirtiness of the road surface (*Richard et al.,2020*). The silt loading rate ranges from arterial to local roads and the measured silt loading ranges (0.03-4.2) g/m^2. The corresponding AP-42 default values (*Fitz, James, David et al., 2020*) range from 0.06 to 0.6 g/m^2. The high value of 4.2 g/m^2 is found on a road with impact from construction activities.

Table 2.5 **Silt-loading rate ($gm/m^2/day$) of Arterial Roads**

Sr. No.	Road type	Peak (Veh./hr)	mean sL ($gm/m^2/day$)	dirtiness (%)	Season	Phase	Net sL ($gm/m^2/day$)
Road 1	Concrete	1548	25	46	Winter	Nearer to Industry	38
Road 2	Concrete	705	3	43	Winter	Nearer to Industry	7.9
Road 3	Bituminous	624	3	60	Winter	Nearer to Industry	9
Road 4	Bituminous	1569	25	55	Winter	Nearer to Industry	44.8
Road 5	Bituminous	1392	25	63	Winter	Nearer to Industry	47.5
Road 6	Concrete	888	3	65	Winter	Nearer to Industry	12.6
Road 7	Concrete	1341	25	70	Winter	Nearer to Industry	49
Road 8	Bituminous	264	3	65	Winter	Nearer to Industry	10
Road 9	Bituminous	738	3	60	Winter	Nearer to Industry	9
Road 10	Bituminous	255	3	70	Winter	Nearer to Industry	10
Road 11	Bituminous	627	3	70	Winter	Construction stage	14
Road 12	Bituminous	54	3	80	Winter	Nearer to Industry	12

Table 2.6 **Silt-loading rate (gm/m²/day) of Collector Roads**

Sr.No.	Road type	Peak (Veh./hr)	mean sL (gm/m²/day)	dirtiness (%)	Season	Phase	Net sL (gm/m²/day)
Road A	Concrete	1035	25	75	Summer	Nearer to Industry	39
Road B	Bituminous	102	3	80	Summer	Nearer to Industry	7.6
Road C	Bituminous	561	3	65	Summer	Nearer to Industry	5.9
Road D	Bituminous	471	3	75	Summer	Construction	8
Road E	Bituminous	1095	25	45	Summer	Construction	29
Road F	Concrete	663	3	40	Summer	Nearer to Industry	5.1
Road G	Concrete	414	3	45	Spring	Nearer to Industry	5.8
Road H	Concrete	966	3	47	Summer	Nearer to Industry	4.9
Road I	Bituminous	738	3	55	Summer	Nearer to Industry	4.6
Road J	Bituminous	981	3	50	Summer	Nearer to Industry	4.4
Road K	Bituminous	1101	25	60	Winter	Nearer to Industry	42
Road L	Bituminous	204	3	70	Spring	Nearer to Industry	6.2
Road M	Bituminous	1098	25	65	Summer	Nearer to Industry	34
Road N	Concrete	981	3	68	Summer	Nearer to Industry	6.9
Road P	Concrete	774	3	68	Summer	Nearer to Industry	6.8
Road Q	Bituminous	312	3	78	Spring	Nearer to Industry	6.7
Road R	Bituminous	96	25	85	Spring	Nearer to Industry	39
Road S	Bituminous	222	3	70	Spring	Nearer to Industry	6.4
Road T	Bituminous	285	3	75	Summer	Nearer to Industry	6.3
Road U	Bituminous	273	3	75	Summer	Nearer to Industry	4.8
Road V	Bituminous	228	3	50	Summer	Nearer to Industry	3.8
Road W	Bituminous	306	3	70	Winter	Nearer to Industry	12
Road Y	Bituminous	36	3	75	Spring	Nearer to Industry	11
Road Z	Concrete	246	3	63	Summer	Nearer to Industry	7.6
a	Bituminous	348	3	78	Summer	Nearer to Industry	7
b	Concrete	126	3	35	Winter	Nearer to Industry	6.3
g	Bituminous	60	3	65	Winter	Nearer to Industry	10
y	Bituminous	447	3	70	Spring	Nearer to Industry	10
F	Concrete	159	3	22	Spring	Nearer to Industry	4.2

2.4.3 Road Dust Resuspension due to varying speed of vehicular stream:

Apart from weight of vehicles, pavement characteristics (either paved or unpaved) and silt fraction, another factor attributing to road dust resuspension is speed of vehicles' stream expressed as PM_{10} in terms of (gm/Veh/Km) :

$C_{res} = 0.014X$ (independent of vehicle category) (*Etyemezian, Gillette et al., 2004*) (2.3)

where,

C_{res} : Concentration of resuspended road dust due to vehicles' speed (gm/Veh/Km)

X : Speed of every individual vehicle (Km/hr)

Table 2.7 **Vehicular category with speed (Km/hr) distribution**

Category of Vehicle	Traffic Volume (Veh/hr)	Maximum Speed (Km/hr)	Minimum Speed (Km/hr)	Mean Speed with deviation (Km/hr)
2W	15201	55	11	42 ± 15
3W	2916	39	11	23 ± 9
4W	4551	111	11	58 ± 23
LMV	684	24	11	18 ± 9
HMV	693	41	11	22 ± 7
ORV	282	30	11	18 ± 4

2.4.4 Total Particulate matters concentrations from transport sector emissions:

In order to get total amount of particulate matters concentration in (gm/hr), the pollutants' concentrations (gm/Veh/Km) including tailpipe emissions, road dust resuspension concentrations due to silt-fraction on road surface and due to free flow speed of vehicular stream emitting from all category of vehicles recorded during real time traffic volume monitoring is multiplied with length (Km) of respective road stretch and summed up.

2.4.5 Average Emission Factor (gm/Veh/Km):

Then total pollutants concentration is divided by total number of vehicles (Veh/hr) and entire length (Km) of road network of entire GIDC of area 4.41 Km^2 in order to get average value of emission factor (gm/Veh/Km) i.e.,

$$\frac{Total\ vehicular\ pollutants\ concentration\ across\ GIDC, Pandesra\ (\frac{gm}{hr})}{Total\ traffic\ volume\ (\frac{Veh}{hr}) * Summation\ of\ length\ of\ all\ road\ stretch\ (Km)} \quad (2.4)$$

Average emission factor is calculated for both peak hour traffic volume and non-peak hour traffic volume (Veh/hr), greater value is considered.

2.4.6 Turbulence of resuspended road dust plume:

Due to varying speeds of vehicles stream on the road, the traction between vehicle fleet tyres and surface road (either paved or unpaved) leads to turbulence of road dust causing dispersion in the atmosphere. The turbulent wake height is defined as the height up to which dust plume is raised from ground surface to the atmosphere. The height at which dust plume is completely mixed is known an injection height which is assumed to be equivalent to turbulent wake height (*Etyemezian, Gillette et al.,2004*).

Height of different of vehicles are shown in *table 2.8*

The turbulent wake height for every individual vehicles = 1.7 * Vehicle height (*Etyemezian, Gillette et al.,2004*) (2.5)

Table 2.8 **Maximum height of different category of vehicles**

Vehicle Category	Maximum height of respective mode of Vehicle (m)
2W	1.17
3W	1.70
4W	2.21
LMV	2.70
HMV	3.45
ORV (JCB)	3.90

Turbulent wake height also depends upon certain conditions, such as atmospheric conditions should be stable, shape and size of the vehicle, angle of ambient wind with respect to direction of the vehicle. If atmospheric condition is stable, the value of turbulent wake height and injection height will be equal. Otherwise, injection height will be much more than turbulent wake height (*Etyemezian, Gillette et al.,2004*).

2.5 Limitations:

i. A few vehicles had not been registered at the R.T.O. and did not have pollution verified certificates which yield to the lack of data regarding fuel norms, engine displacement volume (cc), unloaded weight of vehicles and emission control limits etc.
ii. Effect of wind action on vehicular emission was not considered.
iii. Effect of axle width of vehicles on road dust resuspension was not considered.
iv. Some resuspended dust particles settle down due to the rainfall precipitation.
v. Traffic volume monitoring was done manually through video recording and very labour intensive, may not be fully accurate.

3. Results and Discussions

Pandesara, GIDC road network consists of forty-one number of road stretches, a number of nodes and connectors among which there are twelve arterial roads and twenty-nine collector roads. Population density as well as vehicular population is higher in this zone due to bulk numbers of industries covering the entire area. There are a number of two-lane-one-way roads, two-lane-two-way roads, three-lane-two-way roads and four-lane-two-way roads mentioned in *table (3.1)* and *table (3.2)* which also leads to variation in traffic capacity of different stretches of road network. Traffic volume monitoring was covered in November and December months (winter season), January and February months (spring season), March and April (summer season). Traffic volume monitoring was also taken for two periods, i.e., peak hour and non-peak hour. Peak hour during morning was around 9:00 am to 10:00 am i.e., school and office hour and during evening that was from 5:00 pm to 6:00 pm i.e., time to return home from work. Traffic volume was found to be highest i.e., 1569 Veh/hr in road-4 during peak hour because it connects to the national highway ahead and bears much transportation load. Non-peak hour was around 2:00 pm to 2:30 pm afternoon i.e., the lunch and rest hours. Traffic volume during non-peak hour was found to be least i.e., 8 Veh/hr in road-‘**g**’ connecting to the slum area.

Silt loading rate was found to be highest i.e., 49 $gm/m^2/day$ in road-7 due to higher traffic volume, smooth surface concrete pavement, nearer to industry and monitoring was conducted in winter season and least i.e., 3.8 $gm/m^2/day$ in road-V due to less traffic volume, irregular surface bituminous pavement, nearer to industry and monitoring was conducted in summer season. Maximum speed of vehicles was found in road-L since it is four-lane-two-way having road width 14.3 m, undivided and the road stretch is about 0.36 Km long. Silt-loading rate was also found to be higher in road-10 because it bears transportation of higher numbers of coal loaded vehicles. Summation of length of all road stretches is about 15.77 Km. Traffic volume monitoring for each road stretch was conducted for 20 minutes. In order to find out the total particulate emission in (grams per hour), it was multiplied with ‘3’ and the length of respective road stretch.

3.1) Computation of Pollutants emitted from vehicles:

Table 3.1 **Tailpipe Emission (Peak hour) (9:00-10:00) am or (5:00-6:00) pm**

Vehicle Class	Number of vehicles (20 min.)	Traffic volume (Veh/hr)	Tailpipe Emission (gm/hr)	10% excess (gm/hr)
2W	5067	15201	299.34	329.27
3W	972	2916	72.68	79.95
4W	1517	4551	51.24	56.36
LMV	228	684	102.75	113.03
HMV	231	693	7.29	65.60
ORV	94	282	131.61	144.77
Total	8109	24327	717.25	788.97

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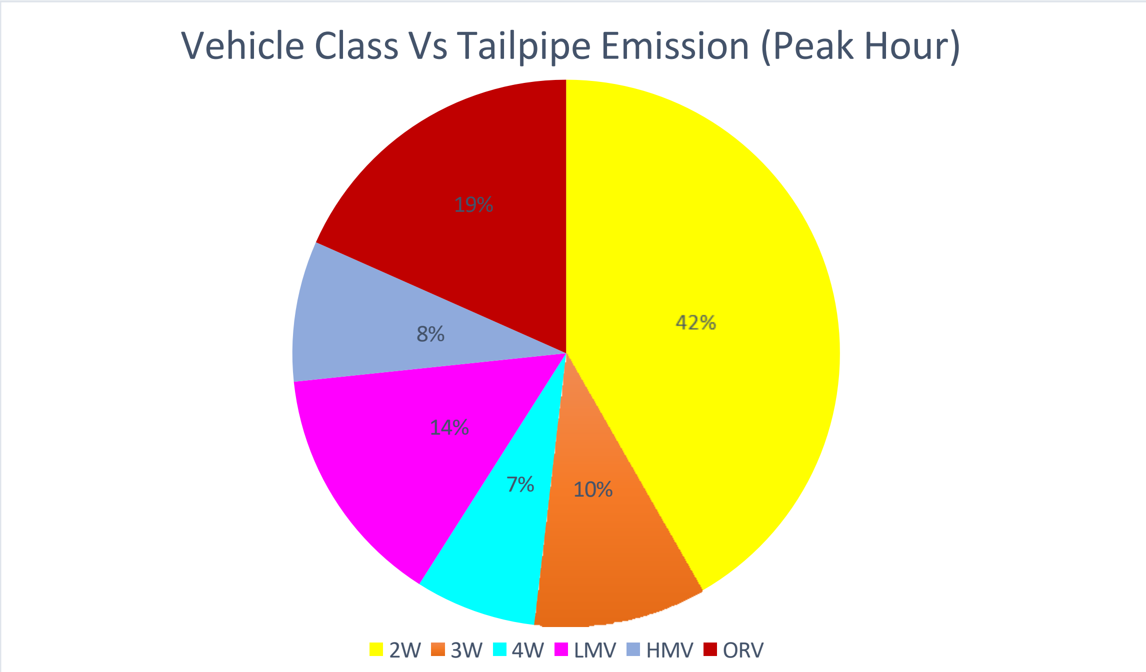

Fig 3.1 Pie-Chart (Vehicle class Vs Tailpipe Emissions (gm/hr) (Peak Hour)

During peak hour, traffic volume was the highest in 2 wheelers followed by 4 wheelers, 3 wheelers, heavy motor vehicles, light motor vehicles and the least in off-road vehicles as shown in *table 3.1*. Tailpipe emission was the highest in 2 wheelers followed by the off-road vehicles (Tractor & JCB), LMV, 3 wheelers, HMV, and the least in 4 wheelers as shown in *table 3.1* and *fig 3.1*. Off road vehicles could have highest tailpipe emission of all, but 2 wheelers exceeded due to highest traffic volume (Vehicles/hour)

Table 3.2 **Aggregated RDS Concentrations (silt-load) (Peak Hour)**

Vehicle class	Traffic Volume (Veh./hr)	Mean Weight of Vehicles (tons)	Maximum Weight of Vehicles (tons)	PM_{10} (gm/hr)
2W	15201	0.30	0.97	25163.80
3W	2916	2.53	3.82	16511.70
4W	4551	7.41	10.72	45724.50
LMV	684	6.67	11.95	23034.80
HMV	693	40.00	190.00	118131.00
ORV (JCB)	282	9.00	12.00	10016.60
Total	24327	27.00	190.00	246986.00

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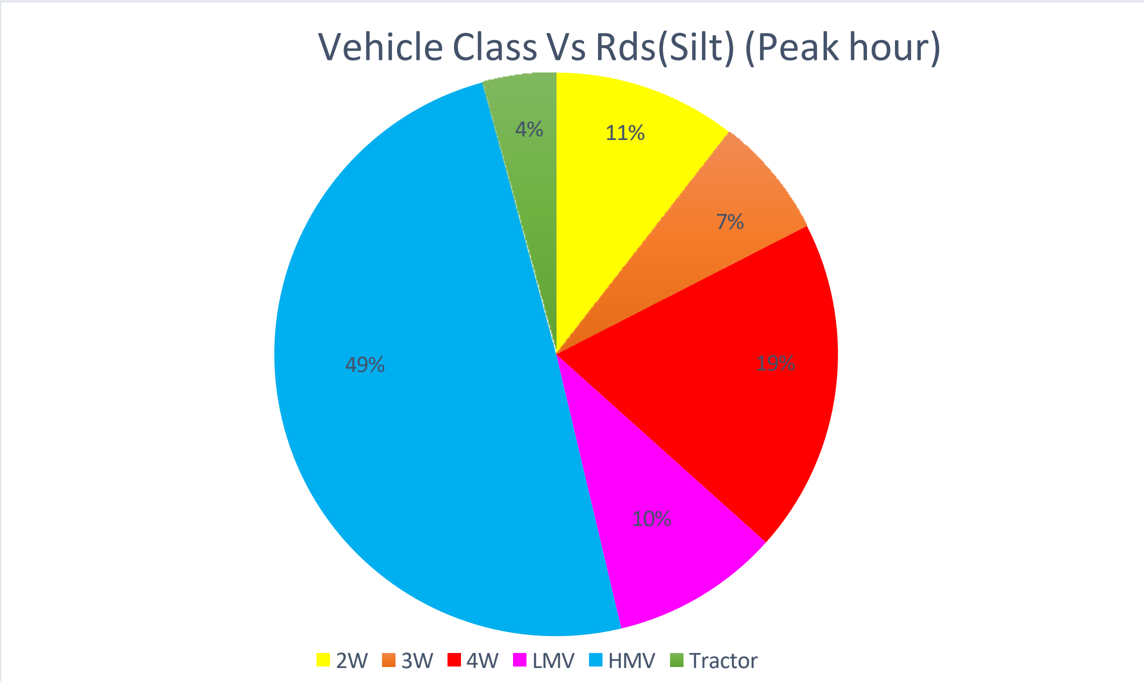

Fig 3.2 (Vehicle class Vs Road dust resuspension (silt load) (gm/hr)) (Peak Hour)

Road-dust resuspension due to silt fraction and vehicular weight during peak hour was the highest in heavy motor vehicles (HMV) followed by 4 wheelers, 2 wheelers, light motor vehicles (LMV), 3 wheelers and the least in off-road vehicles owing to least traffic volume as shown in *table 3.2* and *fig. 3.2* as well.

Table 3.3 **Road Dust Resuspension Concentrations due to Speed (Peak Hour)**

Class	Traffic Volume (Veh/hr)	Maximum Speed (Km/hr)	Minimum Speed (Km/hr)	Mean Speed with deviation (Km/hr)	PM_{10} (gm/hr)
2W	15201	55	11	42 ± 15	2721.42
3W	2916	39	11	23 ± 9	437.39
4W	4551	111	11	58 ± 23	837.47
LMV	684	24	11	18 ± 9	103.45
HMV	693	41	11	22 ± 7	101.98
ORV	282	30	11	18 ± 4	28.25
Total	24327	111	11	50±9	3841.45

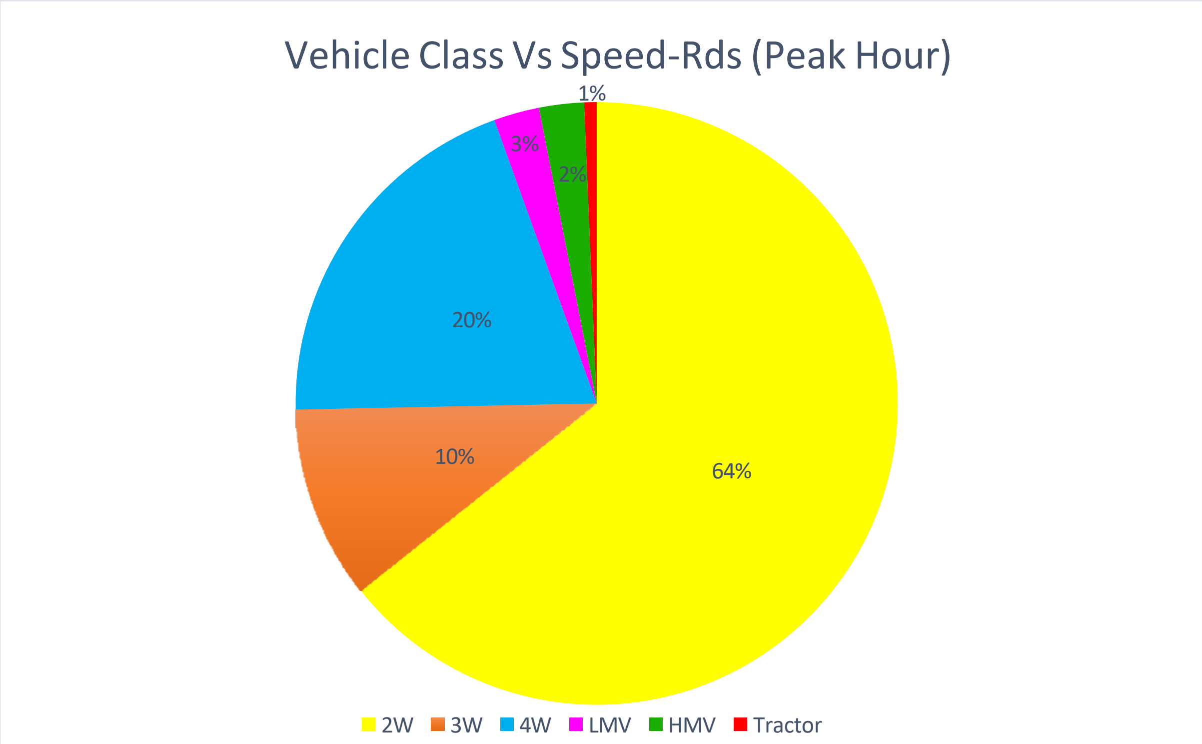

Fig 3.3 (Vehicle class Vs Road dust resuspension due to Speed (gm/hr)) (Peak Hour)

During peak hour, maximum speed as well as average speed were found to be highest in 4 wheelers, road-dust resuspension concentration due to speed of vehicles' stream was highest in 2 wheelers followed by 4 wheelers, 3 wheelers, light motor vehicles, heavy motor vehicles and least in off-road vehicles as shown in *table 3.3* and *fig. 3.3*. Four wheelers could have highest road dust resuspension owing to free flow speed, but 2 wheelers exceeded due to their highest traffic volume.

Table 3.4 **Tailpipe Emission (gm/hr) (Non-Peak Hour) (2:00 to 2:30) pm**

Vehicle Class	Number of vehicles (20 min.)	Traffic volume (Veh./hr)	Tailpipe Emission (gm/hr)	10% Excess (gm/hr)
2W	510	1530	36.48	40.13
3W	110	330	10.89	11.98
4W	189	567	4.24	4.66
LMV	47	141	17.95	19.75
HMV	51	153	7.07	7.78
JCB	32	96	44.39	48.83
Total	938	2814	121.03	133.13

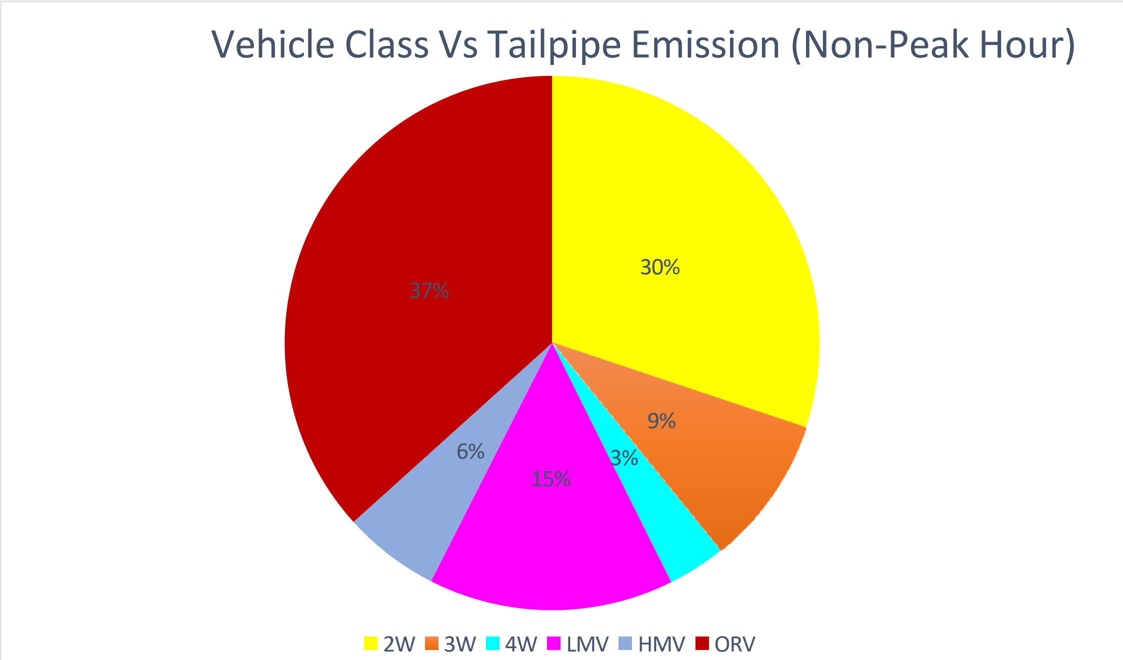

Fig.3.4 Pie-Chart (Vehicle class Vs Tailpipe Emissions (gm/hr) (Non-Peak Hour)

During non-peak hour, traffic volume was found to be the highest in 2 wheelers followed by 4 wheelers, 3 wheelers, heavy motor vehicles, light motor vehicles and the least in off-road vehicles as shown in *table 3.4*. Tailpipe emission was the highest in off-road vehicles (JCB) followed by 2 wheelers, light motor vehicles, 3 wheelers, heavy motor vehicles where as it was the least in 4 wheelers as shown in *table 3.4* and *fig. 3.4*.

Table 3.5 **Aggregated Road Dust Resuspension Concentration (silt-load) (Non-Peak)**

Vehicle class	Traffic Volume (Veh./hr)	Mean Weight of Vehicles (tons)	Maximum Weight of Vehicles (tons)	PM_{10} (gm/hr)
2W	1530	0.30	0.97	3692.31
3W	330	2.53	3.82	1672.18
4W	567	7.41	10.72	4640.49
LMV	141	6.67	11.95	6493.80
HMV	153	40.00	190.00	14472.80
ORV(JCB)	96	9.00	12.00	3184.62
Total	2813	27.00	190.00	34156.16

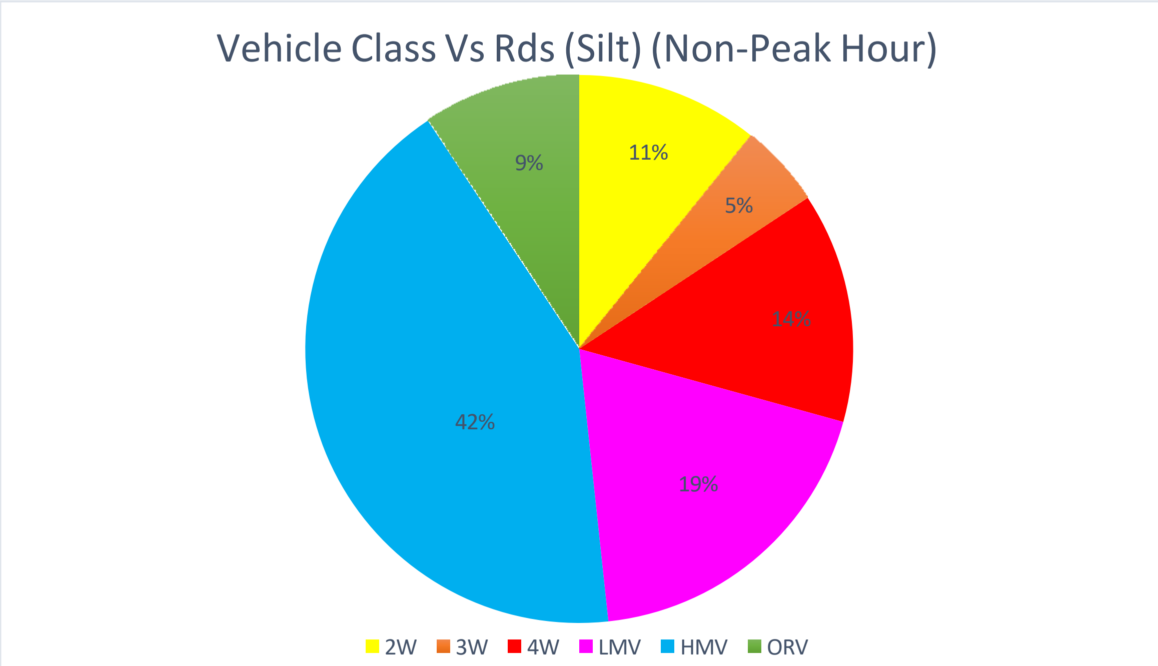

Fig 3.5 (Vehicle class Vs Road-dust resuspension due to silt-load) (Non-Peak Hour)

During non-peak hour, the road dust resuspension due to silt fraction and weight of vehicles was the highest in heavy motor vehicles followed by light motor vehicles, 4 wheelers, 2 wheelers, off road vehicles and the least in 3 wheelers as shown in *table 3.5* and *fig.* 3.5 as well.

Table 3.6 **Road Dust Resuspension Concentrations (Speed) (Non-Peak Hour)**

Vehicle Class	Traffic volume (Vehicles/hour)	Maximum Speed (Km/h)	Minimum Speed (Km/hr)	Mean Speed with deviation (Km/h)	PM_{10} (gm/hr)
2W	1530	46	11	31.33 ± 15	310.78
3W	330	39	11	29.50 ± 9	56.75
4W	567	105	11	37.43 ± 23	136.63
LMV	141	47	11	26.22 ± 9	24.74
HMV	153	35	11	26.50 ± 7	24.84
ORV	96	20	11	18.00 ± 4	14.69
Total	2813	105	11	25 ± 6	568.43

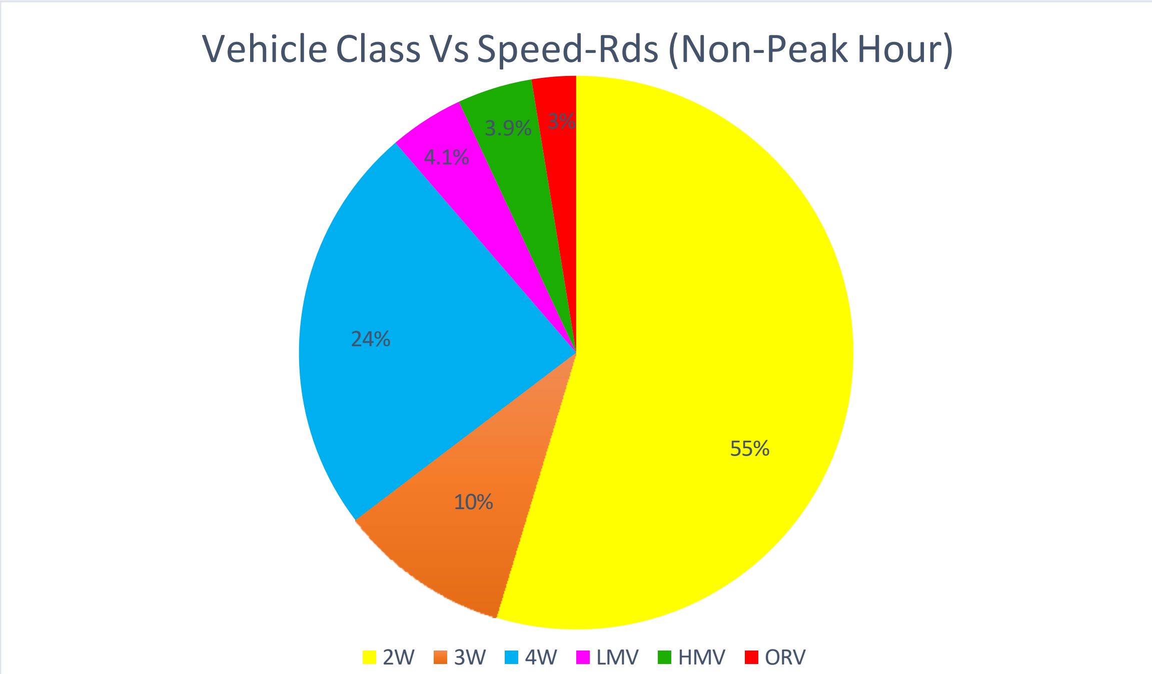

Fig 3.6 (Vehicle class Vs Road-dust resuspension (speed) (gm/hr)) (Non-Peak Hour)

During non-peak hour, average speed as well as maximum speed were found to be highest in 4 wheelers as shown in *table 3.6* and road dust resuspension due to speed of vehicles' stream was the highest in 2 wheelers as shown in *fig.* 3.6 followed by 4 wheelers, 3 wheelers, light motor vehicles, heavy motor vehicles, off road vehicles, 3 wheelers and the least in off-road vehicles owing to least traffic volume. 4 wheelers could have the highest amount of road dust resuspension owing to speed of vehicular stream, but 2 wheelers exceeded due to their highest traffic volume.

Table 3.7 **Summation of PM concentrations (gm/hr) from vehicles (Peak Hour)**

Vehicle Class	Tailpipe Emission PM (gm/hr)	PM_{10} (silt) (gm/hr)	PM_{10} (speed) (gm/hr)	Total PM (gm/hr)
2W	329.27	25163.80	2721.42	28214.50
3W	79.95	16511.70	437.39	17029.00
4W	56.36	45724.50	837.47	46618.30
LMV	113.03	23034.80	103.45	23251.30
HMV	65.60	118131.00	101.98	118299.00
ORV	144.77	10016.60	28.25	10189.60
Total	788.97	246986.00	3841.45	251616.00

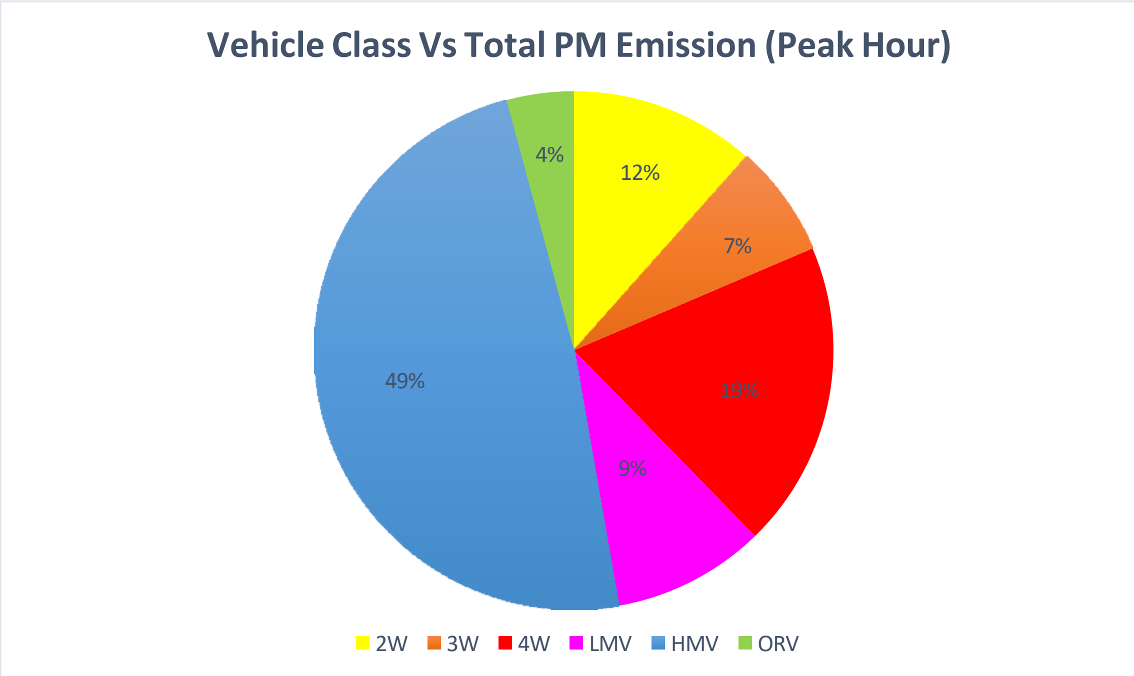

Fig 3.7 (Vehicle class Vs Total PM emission (gm/hr)) (Peak Hour)

During peak hour, total particulate emissions (gm/hr) due to all modes of vehicles was found to be the highest in heavy motor vehicles followed by 4 wheelers, 2 wheelers, light motor vehicles, 3 wheelers and least in off-road vehicles owing to their least traffic volume as shown in *table 3.7* and *fig. 3.7* as well.

Table 3.8 **Total PM concentration (gm/hr) from vehicles (Non-Peak Hour)**

Vehicle Class	Tailpipe Emission PM (gm/hr)	PM_{10} (silt) (gm/hr)	PM_{10} (speed) (gm/hr)	Total PM (gm/hr)
2W	40.13	3692.31	310.78	4043.22
3W	11.98	1672.18	56.75	1740.91
4W	4.66	4640.49	136.63	4781.78
LMV	19.74	6493.80	24.74	6538.28
HMV	7.78	14472.80	24.84	14505.40
ORV	48.83	3184.62	14.69	3248.14
Total	133.13	34156.16	568.43	34857.70

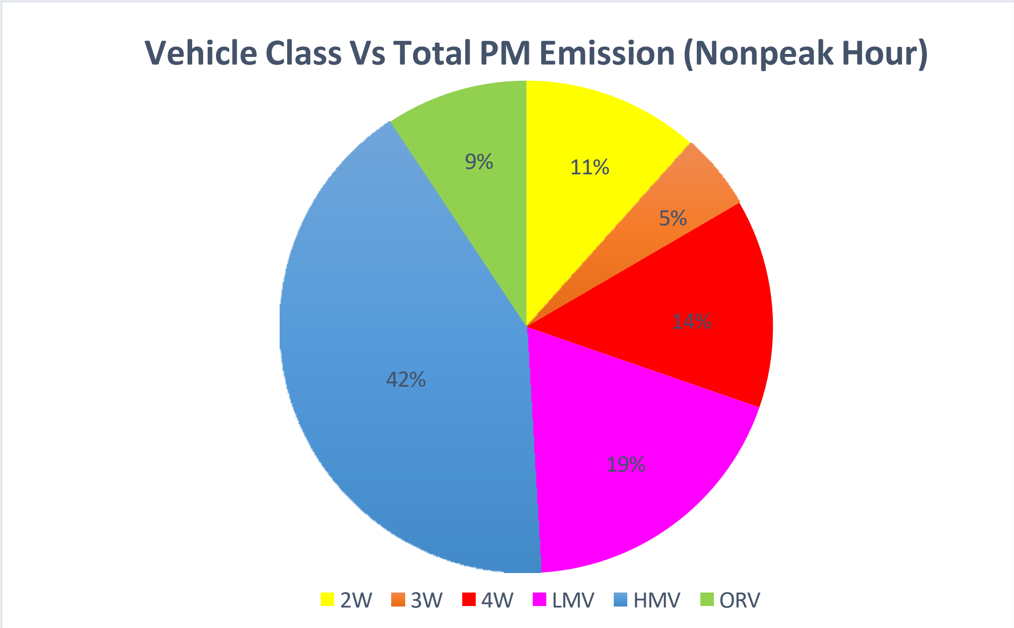

Fig 3.8 (Vehicle class Total PM emission (gm/hr)) (Non-Peak Hour)

Total Particulate emissions (gm/hr) due to all vehicles' category was found to be highest in heavy motor vehicles as shown in *table 3.8* and *fig. 3.8* followed by light motor vehicles, 4 wheelers, 2 wheelers, off road vehicles and least in 3 wheelers during non-peak hour.

3.2) <u>Comparison between pollutants concentration of peak hour and non-peak hour</u> :

Table 3.9 **Comparison between aggregated emissions of both periods**

Vehicle Class	Peak Hour Emission (gm/hr)	Non-Peak Hour Emission (gm/hr)
2W	28214.50	4043.22
3W	17029.00	1740.91
4W	46618.30	4781.78
LMV	23251.30	6538.28
HMV	118299.00	14505.40
ORV	10189.60	3248.14
Total	251616.00	34857.70

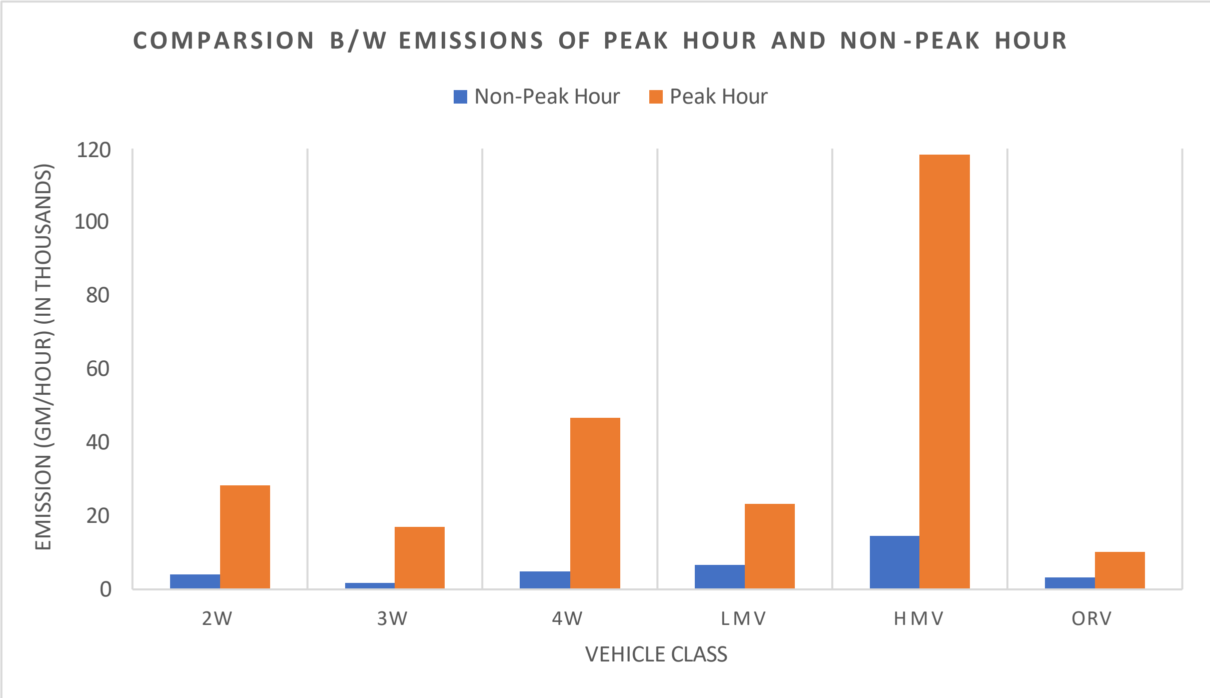

Fig 3.9 Comparison between aggregated emissions of both periods

Total Pollutants were found to be 251616 gm/hr during peak hour and 34857.7 gm/hr during non-peak hour respectively as shown in *table 3.9 and fig. 3.9*. Hence, the greater value was taken for consideration, i.e., 251616 gm/hr.

3.3) <u>Average Emission Factor</u> :

3.3.1) Average Emission Factor (gm/Veh/Km) during peak hour =

$$\frac{Total\ vehicular\ pollutants\ \ concentration\ across\ GIDC, Pandesra\ \ (\frac{gm}{hr})\ during\ peak\ hour}{Total\ \ traffic\ volume\ (\frac{Veh}{hr})\ during\ peak\ hour * Summation\ of\ length\ of\ all\ road\ stretch\ (Km)}$$

$$= \frac{251616\ (gm)/hr}{(24327\ Veh/hr)*(15.77)\ (Km)}$$

= 0.66 gm/Veh/Km

3.3.2) Average Emission Factor (gm/Veh/Km) during non-peak hour =

$$\frac{Total\ vehicular\ pollutants\ \ concentration\ across\ GIDC, Pandesra\ \ (\frac{gm}{hr})\ during\ non\ peak\ hour}{Total\ \ traffic\ volume\ (\frac{Veh}{hr})\ during\ non\ peak\ hour * Summation\ of\ length\ of\ all\ road\ stretch\ (Km)}$$

$$= \frac{34857.7\ (gm)/hr}{(2813\ Veh/hr)*(15.77)\ (Km)}$$

= 0.79 gm/Veh/Km

The greater value was taken for consideration. Hence, the final value of average emission factor of the vehicular emissions from entire Pandesara area was found to be 0.79 gm/Veh/Km.

3.4) Turbulent Wake Height of Road Dust Plume :

Table 3.10 **Maximum TWH of different Category of Vehicles**

Vehicle Category	Maximum height of respective mode of Vehicle (m)	Maximum Turbulent Wake Height (m)
2W	1.17	1.99
3W	1.70	2.89
4W	2.21	3.76
LMV	2.70	4.59
HMV	3.45	5.86
ORV (JCB)	3.90	6.63

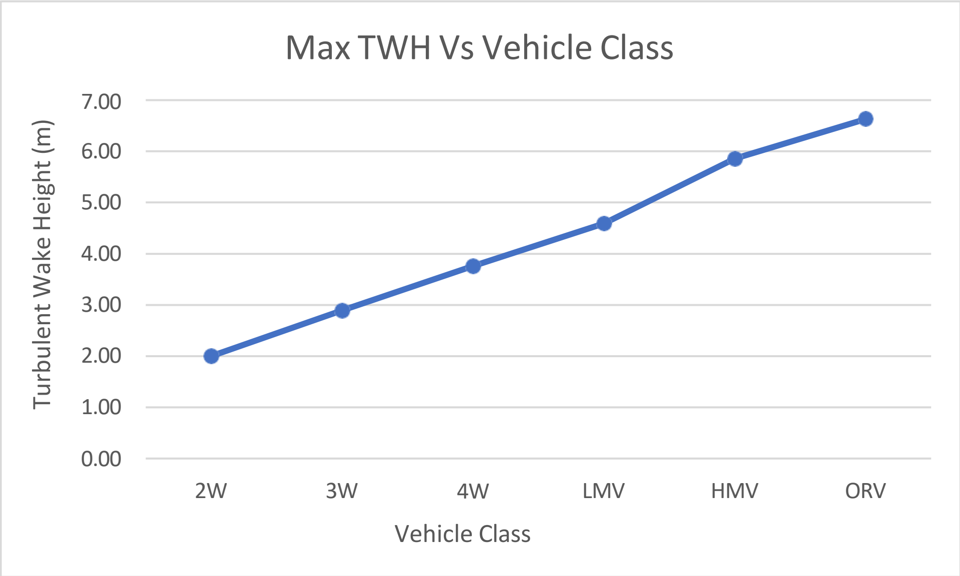

Fig 3.10 Maximum TWH of different Category of Vehicles

The value of turbulent wake height of road dust plume was found to be maximum in off-road vehicles i.e., 6.63 m due to large height of JCB followed by heavy motor vehicles, light motor vehicles, 4 wheelers, 3 wheelers and 2 wheelers respectively as shown in both *table 3.10* and *fig. 3.10.*

Traffic volume was found to be highest in 2 wheelers, followed by 4 wheelers, 3 wheelers, heavy motor vehicles, light motor vehicles and off-road vehicles respectively. Proportion of tailpipe emission was the highest in off-road vehicles. Even their traffic volume was the least of all. Then it was followed by other categories of vehicles in the decreasing order of engine displacement volume (cc) and the increasing order of mileage value irrespective of order of traffic volume.

Road dust resuspension concentrations due to silt fraction of road was the highest in heavy motor vehicles (HMV) followed by other categories of vehicles in the decreasing order of gross vehicular weight. Road dust resuspension concentration due to speed was the highest in 2 wheelers followed by 4 wheelers, 3 wheelers, light motor vehicles, heavy motor vehicles and off-road vehicles respectively irrespective of order of traffic volume. Maximum speed was found in 4 wheelers i.e., 111 Km/hr, they could have led to highest amount of road dust resuspension owing to speed. Since traffic volume of 2 wheelers was much higher than 4 wheelers, they contribute to road dust resuspension owing to speed in maximum amount. This was followed by 3 wheelers, light motor vehicles, heavy motor vehicles and off-road vehicles in the decreasing order of traffic volume.

Turbulent wake height of road dust plume was found to be highest in off-road vehicles followed by other categories of vehicles in the decreasing order of vehicular heights. Total particulate emissions concentrations were found to be highest in heavy motor vehicles (HMV) i.e., 49% of total vehicular emissions. Because road dust resuspension due to silt loading rate was playing a dominant role. Total particulate matter concentrations emitted from vehicles across the entire Pandesara zone was found to be 251616 gm/hr. Average vehicular emission factor for the entire 4.41 Km^2 area of Pandesara zone was found to be 0.79 gm/Veh/Km.

4. CONCLUSION

The study reveals that the total amount of tailpipe emission on entire Pandesara area is 788.97 gm/hr during peak hour and 133.13 gm/hr during non-peak hour. Road dust resuspension due to both silt fraction and vehicular speed is 250827.45 gm/hr during peak hour and 34724.59 gm/hr during non-peak hour respectively. Hence, road dust resuspension occurs 320 times and 260 times greater than tailpipe emission during peak hour and non-peak hour respectively.

Generally, people think that in order to reduce atmospheric pollution, there are two alternatives, either transportation vehicles should be banned or all fuel vehicles should be replaced by electric vehicles. First alternative is not possible because they provide multipurpose facilities such as ease of long-distance travelling, save time, increase in production rate and profit in business. In second alternative, electric vehicles do not give tailpipe emissions but contribute to road dust resuspension in significant amount. Road dust resuspension contributes more than tailpipe emission which is a focus of major concern but awareness among people is negligible not only in India but also worldwide.

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