CHAPTER – 2
LITERATURE SURVEY

2.0 GENERAL

Most of the on road vehicles used hydrocarbon as a fuel. Ideally, in complete combustion of fuel should emit carbon dioxide (CO$_2$) and water (H$_2$O). But in actual practice, the process is quite complex. Therefore, it is important to know sources of vehicular pollution, types of pollutants, the factor that influences combustion chemistry, the effect of driving mode on emissions of pollutants.

2.1 Sources of Vehicular Emission:

Most of the vehicles are propelled by means of internal combustion engines (IC engine). Internal combustion engines can be broadly classified into two types-

(i) Spark ignition (SI) engine (uses petrol or gasoline as fuel), (ii) Compression ignition (CI) engine (uses diesel as fuel).

The vehicular population in India can be categorized into three principal types- (Mukherjee, 1998)

(i) Passengers’ cars powered by four-stroke engine, (ii) Two and three wheelers powered by small two-stroke gasoline engine, (iii) Buses, trucks and light commercial vehicles powered by four-stroke diesel engines.

There are primarily three sources of emissions in vehicles:

(i) Crankcase blow by.

(ii) Evaporative emissions.

(iii) Exhaust emissions.
2.1.1 Crank Case blow by:

During compression and power stroke the pressure of the gas inside the cylinder is very high and therefore the gas inside the cylinder leaks past the piston and the piston ring into the crankcase which is known as blow by. This mixture contains approximately 85% unburned fuel and 15% exhaust product (Seinfeld, 1980). It increases with the engine wear, as the seal between piston and cylinder becomes less effective. Blow by gases accounts for 25% of total hydrocarbon vehicular emission. In modern cars, the problem is solved by sending the gases to the carburettor or air fuel intake manifold instead of passing to the atmosphere.

2.1.2 Evaporative Emission:

The evaporative emission occurs via fuel tank and carburettor. The evaporation from fuel tank depends on the volatility of the fuel and ambient temperature. The carburettor evaporative losses occur during the ‘hot soak’ period. That occurs when an engine is stopped after a run. At that moment cool air flow stops to the carburettor and the heat of engine warms the carburettor. When the carburettor temperature rises during the heat soak, 30% of this fuel in the float chamber of the carburettor evaporates. The fuel evaporation from both carburettor and fuel tank accounts approximately 19% of total hydrocarbon emission (Nevers, 1995).

2.1.3 Exhaust Emissions:

Ideally complete combustion of hydrocarbon fuel yields only CO₂ and H₂O as the combustion product. Unfortunately under the condition of combustion in an internal combustion engine exhaust gases contain a very complex mixture of materials, which includes the hydrocarbon (HC), oxides of nitrogen (NOₓ), carbon monoxide (CO), particulate matter (PM) etc. The factors that influence combustion chemistry are discussed below (Husselbee, 1984).
Air Fuel Ratio:

For a given quantity of fuel, the precise amount of oxygen required for complete combustion according to the fundamental relationship is (equation 2.1)

$$C_x H_y + (x + 1/4 y) O_2 \rightarrow x CO_2 + 1/2 y H_2O$$ (2.1)

A stoichiometric mixture for a typical gasoline requires about 14.6 parts by weight of air per part by weight of fuel. Figure 2.1 shows effects of air fuel ratio to power and figure 2.2 shows the effect of air fuel ratio on exhaust emissions. Lean mixtures, which contain excess air, produce less amount of HC and CO. But too much lean, such as an air fuel ratio of 17:1 may not ignite properly leading to misfiring and a large amount of HC passes unburned. If the mixture is rich it may lead to the formation of CO and HC more.

Compression Ratio:

Compression pressure is directly related to temperature, a determining factor in the combustion process. Compression ratio causes increase in temperature and fuller burning of charge. This causes a reduction in HC but leads to more NO$_x$ formation.

Figure 2.1: Effect of air-fuel ratio on power and economy
Ignition Timing:

Advance ignition timing increases NO\(_x\) and HC but CO emission decreases. Advance ignition timing increases temperature and pressure inside the cylinder. These factors influence in the increase of NO\(_x\) production but lower the temperature at the exhaust, so the oxidation of hydrocarbon in the exhaust manifolds lowers and increases in HC production.

Idle Speed:

At lower idle speed throttle valve is almost in closed position. This results in the lack of oxygen necessary to maintain the correct mixture for complete combustion. So at low idle speed, there will be an increase in HC and CO production. Table 2.1 shows the effect of intermediate load and high load on different pollutants. It shows that as the load increases emission of pollutant also increases.
Table 2.1: Typical Exhaust Constituent

<table>
<thead>
<tr>
<th>Emission</th>
<th>Engine Type</th>
<th>Idle ppm</th>
<th>Intermediate load ppm</th>
<th>High load ppm</th>
<th>g/Kwh</th>
<th>g/Kwh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbon</td>
<td>SI</td>
<td>4000</td>
<td>2400</td>
<td>7.5</td>
<td>6000</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>CI</td>
<td>200</td>
<td>50</td>
<td>0.5</td>
<td>100</td>
<td>0.3</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>SI</td>
<td>10000</td>
<td>10000</td>
<td>73</td>
<td>60000</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>CI</td>
<td>150</td>
<td>700</td>
<td>3.8</td>
<td>500</td>
<td>5</td>
</tr>
<tr>
<td>Oxides of Nitrogen</td>
<td>SI</td>
<td>100</td>
<td>2500</td>
<td>17</td>
<td>500</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>CI</td>
<td>150</td>
<td>1700</td>
<td>14</td>
<td>1400</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Source: (Agarwal S.K, 1991)

2.1.4 Effects of Driving Mode on Automobile Pollution:

The composition and quantities of emission product from automobiles depend on the mode of driving. When the vehicle cruise at high speed, hydrocarbon and carbon monoxide emission are very low because the mixture is set at slightly lean for the best economy of fuel. But nitric oxide concentration is increased because of high temperature achieved and more oxygen availability. Declaration results in a very high concentration of hydrocarbon and carbon monoxide in the exhaust. When an engine starts from cold, it needs a rich mixture, as the fuel vaporization is slow, so its results in high hydrocarbon and carbon monoxide in the exhaust. Table 2.2 and 2.3 shows emissions of the different pollutants under the different mode of operations.

Table 2.2: Effect of Vehicle operating Mode (VOM) on exhaust emission

<table>
<thead>
<tr>
<th>V.O.M</th>
<th>Exhaust flow</th>
<th>Exhaust concentration HC</th>
<th>CO</th>
<th>NO</th>
<th>Blow By</th>
<th>Evaporation loss Tank</th>
<th>Evaporation loss Carb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idle</td>
<td>Very low</td>
<td>High</td>
<td>High</td>
<td>Very Low</td>
<td>Low</td>
<td>Average to Moderate</td>
<td>Mod</td>
</tr>
<tr>
<td>Cruise:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low speed</td>
<td>Low</td>
<td>Very high</td>
<td>Very high</td>
<td>Low</td>
<td>Mod rate</td>
<td>Small</td>
<td></td>
</tr>
<tr>
<td>High speed</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Mod</td>
<td>High</td>
<td>Nil</td>
<td></td>
</tr>
<tr>
<td>Acceleration</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Mod</td>
<td>Nil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>Very high</td>
<td>Mod</td>
<td>High</td>
<td>Very high</td>
<td>Nil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>De-</td>
<td>high</td>
<td>high</td>
<td>Very low</td>
<td>Very low</td>
<td>Mod</td>
<td></td>
</tr>
<tr>
<td>acceleration</td>
<td>Very low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: (Agarwal S.K, 1991)
Table 2.3: Typical Exhaust Gas Constituents as a Function of Driving Mode

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Idling</th>
<th>Acceleration</th>
<th>Cruising</th>
<th>Deceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide, %</td>
<td>4-9</td>
<td>0-8</td>
<td>1-7</td>
<td>2-9</td>
</tr>
<tr>
<td>Hydrocarbons (as hexane), ppm</td>
<td>500-1000</td>
<td>50-800</td>
<td>200-800</td>
<td>3000-2000</td>
</tr>
<tr>
<td>Oxides of Nitrogen, ppm</td>
<td>10-50</td>
<td>1000-4000</td>
<td>1000-3000</td>
<td>5-50</td>
</tr>
</tbody>
</table>

Source: Seinfeld, (1980)

2.1.5 Vehicle Emission Factor:

Any air quality management programme requires knowledge of the character and rates of emission from pollution sources. The emission factor is essential in predicting air pollution concentration through mathematical models. Vehicular emission factor ($E_f$) is defined as the quantity of a pollutant emitted when a vehicle runs a unit length. If $Q$ is the emission rate per unit length in g/km/hr, then (Equation 2.2)

$$Q = E_f \times \frac{g}{km \times hr}$$  \hspace{1cm} (2.2)

Where,

$E_f$ = emission factor in g/km  
$V_h$ = Vehicle density in number of vehicles/hr

The emission factor depends upon the type, age, driving cycle etc. of the vehicle. The effect of rate of pollutant emission for different modes of driving has been discussed in article 2.15. To determine emission factor the basic approach is to specify exhaust emission rate by an ‘average trip’ that is representative of the average driving habits of the population. The trip is usually termed as driving cycle, which is composed of a series of driving mode (idle, acceleration, cruise, and deceleration), in a predetermined length of time. Figure 2.3 shows the driving cycle of India and Japan (Marathe, 1985).
Figure 2.3: Driving Cycle of India and Japan

Source: Marathe, (1985)

Emission factors can be developed to predict emission per unit of a process or fuel mass or per persons and so on. The product of emission factor with the relevant emission indicator provides an estimate of emission.

### 2.2 EMISSION INVENTORY:

An emission inventory is defined as an accounting of all air pollution emissions and associated data from sources within a specified area and over a specific time interval (Utah DEQ, 2012). Emission Inventory can be developed for various purposes like (i) planning to reduce air pollution, (ii) tracking the progress of controlled measures and (iii) land use and urban planning etc. Emissions from different categories of vehicles at different time frame and of different pollutants mainly CO, NO\textsubscript{X}, PM, SO\textsubscript{2}, HC, CO\textsubscript{2} can be estimated. Different studies have been done to develop emission inventory for different parts of the world.

The CO\textsubscript{2} emission from the transportation sector in India is growing at an alarming rate. As compared to the developed countries, CO\textsubscript{2} emissions will be more than double by 2030 in the developing countries particularly in China and India (EIA, 2008). It is reported that road transportation is
responsible for 80 percent of total emissions from the transportation sector (TEDDY, 2007). Among the different modes of transportation, road traffic contributes maximum as much as 73% of total emissions (CPCB, 2010). It is reported that vehicles in major metropolitan cities of India are estimated to account for 70% of CO, 50% of HC, 30-40% of NO\textsubscript{x}, 35% of SPM and 10% of SO\textsubscript{2} of the total pollution load of the respective pollutants in these cities (Agrawal, A., 2011).

It was reported that globally over 90% of CO in city centres come from vehicles and it is common to find 50-60% of hydrocarbons (HC) and NO\textsubscript{x} coming from these sources (WHO, 1997). In table 2.4 comprehensive data on air pollution from the transportation sector and other activities or shown which is published by the OECD (Organisation for Economic Co-operation and development, 1993) countries. CO and NO\textsubscript{x} are mainly contributed by the transportation sector.

**Table 2.4: Motor vehicle share of OECD pollutant emissions**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Source</th>
<th>1980</th>
<th>1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO\textsubscript{2}</td>
<td>Vehicles</td>
<td>2144</td>
<td>1664</td>
</tr>
<tr>
<td></td>
<td>Fixed Sources</td>
<td>60075</td>
<td>38372</td>
</tr>
<tr>
<td>NO\textsubscript{x}</td>
<td>Vehicles</td>
<td>21613</td>
<td>15845</td>
</tr>
<tr>
<td></td>
<td>Fixed Sources</td>
<td>19629</td>
<td>14538</td>
</tr>
<tr>
<td>CO</td>
<td>Vehicles</td>
<td>122440</td>
<td>72824</td>
</tr>
<tr>
<td></td>
<td>Fixed Sources</td>
<td>40726</td>
<td>31260</td>
</tr>
<tr>
<td>VOC</td>
<td>Vehicles</td>
<td>14309</td>
<td>7947</td>
</tr>
<tr>
<td></td>
<td>Fixed Sources</td>
<td>19871</td>
<td>17890</td>
</tr>
<tr>
<td>PM</td>
<td>Vehicles</td>
<td>1967</td>
<td>1998</td>
</tr>
<tr>
<td></td>
<td>Fixed Sources</td>
<td>16038</td>
<td>12512</td>
</tr>
</tbody>
</table>

Source: (WHO, 1997)

Emissions calculated for different types of road transport vehicles of Indian transportation sectors are presented Table 2.5. It is reported that
among the different type of vehicles, truck and Lorries contributed 28.8% of CO$_2$, 39% NO$_x$, and 27.3% SO$_2$ and 25% PM, which constituted 25% of total vehicular emission of India (Ramachandra, and Shwetmala, 2009).

**Table 2.5: Emissions from different types of road transport vehicles in India (Gg)**

<table>
<thead>
<tr>
<th>Categories</th>
<th>CO$_2$</th>
<th>CO</th>
<th>NO$_x$</th>
<th>CH$_4$</th>
<th>SO$_2$</th>
<th>PM</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>28748.16</td>
<td>207.26</td>
<td>679.73</td>
<td>5.02</td>
<td>79.24</td>
<td>31.36</td>
<td>51.72</td>
</tr>
<tr>
<td>Omni Buses</td>
<td>8508.42</td>
<td>60.94</td>
<td>200.53</td>
<td>1.49</td>
<td>23.45</td>
<td>9.28</td>
<td>15.11</td>
</tr>
<tr>
<td>Two wheelers</td>
<td>8701.08</td>
<td>719.64</td>
<td>62.15</td>
<td>58.86</td>
<td>4.25</td>
<td>16.36</td>
<td>464.49</td>
</tr>
<tr>
<td>LMV (passenger)</td>
<td>4378.10</td>
<td>370.29</td>
<td>92.93</td>
<td>13.07</td>
<td>2.11</td>
<td>14.52</td>
<td>10.16</td>
</tr>
<tr>
<td>Taxi</td>
<td>2367.08</td>
<td>10.23</td>
<td>5.68</td>
<td>0.11</td>
<td>117.05</td>
<td>0.80</td>
<td>1.48</td>
</tr>
<tr>
<td>Trucks (Goods)</td>
<td>44654.56</td>
<td>442.04</td>
<td>110.94</td>
<td>7.80</td>
<td>123.08</td>
<td>17.33</td>
<td>12.13</td>
</tr>
<tr>
<td>Trailers &amp; tractors</td>
<td>46563.85</td>
<td>460.94</td>
<td>115.69</td>
<td>8.13</td>
<td>128.43</td>
<td>18.08</td>
<td>12.65</td>
</tr>
<tr>
<td>Others</td>
<td>5705.22</td>
<td>57.41</td>
<td>64.54</td>
<td>1.83</td>
<td>32.19</td>
<td>3.98</td>
<td>8.96</td>
</tr>
</tbody>
</table>


Different researchers and agencies in Indian context estimated emission inventory for several big cities like Nagpur, Jamshedpur, and Delhi etc.

Total emissions of CO, NO$_x$, and PM from different types of vehicles in Delhi were found to be approximately 509.6, 193.7 and 14.62 tons/day, respectively during the year 2008-09 and have been shown in table 2.6 (Goyal, et al., 2013). Further, Goyal *et al.*, (2013) reported that the emissions of CO, NO$_x$ and PM were higher due to 2 wheelers, personal cars and heavy commercial vehicles, respectively (Figure 2.4).
Table 2.6: Emissions (Tons/day) from each type of vehicle in Delhi

<table>
<thead>
<tr>
<th>Fleet</th>
<th>CO</th>
<th>NOx</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2W</td>
<td>311.2</td>
<td>5.8</td>
<td>0.40</td>
</tr>
<tr>
<td>3W</td>
<td>14.4</td>
<td>34.5</td>
<td>.01</td>
</tr>
<tr>
<td>PC</td>
<td>173.5</td>
<td>98.2</td>
<td>.012</td>
</tr>
<tr>
<td>Bus</td>
<td>4.5</td>
<td>11.8</td>
<td>0.01</td>
</tr>
<tr>
<td>LCV</td>
<td>6.7</td>
<td>3.2</td>
<td>0.06</td>
</tr>
<tr>
<td>HCV</td>
<td>3.26</td>
<td>40.2</td>
<td>13.48</td>
</tr>
<tr>
<td>Total</td>
<td>509.6</td>
<td>193.7</td>
<td>14.62</td>
</tr>
</tbody>
</table>

Source: (Goyal, et al., 2013)

Figure 2.4: Vehicle wise emissions of pollutants in Delhi (Goyal, 2013)

The same study also reported (figure 2.4) that in Delhi the contribution of CO is 61% by 2 wheelers and 34% by cars of total vehicular emissions of CO and on the other hand NOx contribution was 50% by cars and 21% for heavy commercial vehicles. In the context of PM, 92% was contributed by heavy commercial vehicles while very small and negligible amount was contributed by 3 wheelers and buses since CNG is used in most of these vehicles. The comparative vehicular emissions in Delhi for different year reviewed by Goyal, et al., (2013) are shown in table 2.7.
Table 2.7: Comparative analysis of vehicular emissions (tons/day) from different studies

<table>
<thead>
<tr>
<th>Studies (Place-fuel)</th>
<th>CO</th>
<th>NOx</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kansal, et al., (2011) (ITO-all fuel) for year 2004-05</td>
<td>-</td>
<td>0.74</td>
<td>2.89</td>
</tr>
<tr>
<td>IIT Delhi study (ITO-all fuel) for the years 2008-09 as reported by Goyal et. al.,(2013)</td>
<td>14.89</td>
<td>5.87</td>
<td>0.49</td>
</tr>
<tr>
<td>Nagpure, et al., (2011) (Delhi petrol) for average values of years 1995-2005</td>
<td>216.45</td>
<td>9.85</td>
<td>-</td>
</tr>
<tr>
<td>IIT Delhi study (Delhi petrol) for the year 2008-09 as reported by Goyal et.al.(2013)</td>
<td>397.75</td>
<td>54.90</td>
<td>0.45</td>
</tr>
<tr>
<td>Gurjar, et al., (2004) (Delhi-all fuel) for the year 2000</td>
<td>1210.47</td>
<td>363.98</td>
<td>76.52</td>
</tr>
<tr>
<td>IIT Delhi study (Delhi all fuel) for the year 2008-09 as reported by Goyal, et.al.,(2013)</td>
<td>506.62</td>
<td>193.46</td>
<td>14.59</td>
</tr>
</tbody>
</table>


A study conducted by Wang et al., (2008) showed that total vehicular emissions of HC, CO and NOx were 13.33X10^4, 100.02X10^4 and 7.55X10^4 tons in Beijing urban area in the year 2005. They also recorded higher emission of CO and CO₂ due to personal cars followed by trucks and taxi (table 2.8).

Table 2.8: Emissions contribution of each vehicle type, 10^4 tons
(Beijing, 2005)

<table>
<thead>
<tr>
<th>Fleet</th>
<th>CO</th>
<th>VOC</th>
<th>NOx</th>
<th>PM</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck</td>
<td>12.70</td>
<td>1.09</td>
<td>3.39</td>
<td>0.11</td>
<td>215.45</td>
</tr>
<tr>
<td>Bus</td>
<td>5.29</td>
<td>0.53</td>
<td>2.59</td>
<td>0.03</td>
<td>137.29</td>
</tr>
<tr>
<td>MC/MP</td>
<td>9.01</td>
<td>3.48</td>
<td>0.20</td>
<td>0.09</td>
<td>42.12</td>
</tr>
<tr>
<td>Taxi</td>
<td>12.66</td>
<td>1.10</td>
<td>0.96</td>
<td>0.00</td>
<td>189.95</td>
</tr>
<tr>
<td>PC/LDT</td>
<td>17.40</td>
<td>1.55</td>
<td>2.06</td>
<td>0.02</td>
<td>581.88</td>
</tr>
</tbody>
</table>

Source: Wang et al. (2008)
The CO$_2$ emissions for Indian roads are estimated by Central Pollution Control Board (CPCB, 2010) and the findings are presented in figure 2.5.

Mittal, M.L., and Sharma, C. (2003) have reported CO$_2$ emission for the mega city Delhi due to vehicular traffic for the year 1997 as 5460 Gg (54.6 lakh tons).

Gurjar, at el. (2004) has estimated the emission trend during the year 1990-2000 and observed that emission of CO$_2$ in the mega city Delhi as 22 Tg (22×10$^6$ tons) for the year 2000. This study incorporates the emission from the power plant, transport sector, and domestic fuel etc.

Sharma, C. and Pundir, R (2008) also studied inventory of green house gases and other pollutants from the transport sector for the city of Delhi. They observed that CO$_2$ emissions from the gasoline driven vehicle in Delhi during the year 1999-00 were 11.87 lakh tons and diesel driven light commercial vehicle was 97.79 lakh tons for the same year.
2.3 TYPES OF MODELS:

Vehicular pollution models can be defined as a mathematical techniques or methodology based on physical principles for estimating pollutant concentration in space and/or time for a given set of emissions and meteorological conditions.

Air pollution dispersion modelling is the mathematical simulation of how air pollutants disperse in the ambient atmosphere. It is performed with computer programs, that solve the mathematical equations and algorithms which simulate the pollutant dispersion. The dispersion models are used to estimate or to predict the downwind concentration of air pollutants emitted from emission sources such as industrial plants and vehicular traffic. These models are important to governmental agencies tasked with protecting and managing the ambient air quality. The models also serve to assist in the design of effective control strategies to reduce emissions of harmful air pollutants (Singh et al., 2006). The Air pollution models are one of the most important components of an urban air quality management plan, it provides a means to assess the current and future air quality in order to make policy decisions.

Most of the dispersion models require the input of data which includes:

(i) Meteorological conditions such as wind speed and direction, the amount of atmospheric turbulence (as characterized by what is referred to as the stability class), the ambient air temperature and the height to the bottom of any temperature inversion that may be present aloft.

(ii) Emissions parameters such as traffic volume, type of vehicle, emission factors etc.
(iii) Terrain elevations at the source location and at the receptor location. The location, height and width of any obstructions (such as buildings or other structures) in the path of the gaseous emission plume.

There are several ways of classifying the existing models according to their specific attributes (Sharma, 2004). The most important criteria being:

(i) Source – Receptor relationship: source – oriented (point, area, line, volume) and receptor – oriented (street canyon, intersection model etc.)

(ii) Basic model structure: deterministic or non-deterministic, steady state or time dependent

(iii) Frame of reference: Eulerian or Lagrangian

(iv) Dimensionality of computational domain: one dimensional, two dimensional, three dimensional or multi dimensional

(v) Scale (space and time): microscale (1m, sec-min), mesoscale (5-10 km, hour), small synoptic (100 km, hour-day), large synoptic (100 – 1000 km, days) and planetary (>1000 km, weeks)

(vi) Model structure and the approach: used for the closure of the turbulent diffusion equation (closed-form, analytical and numerical, statistical and physical)

(vii) The terrain/area: to which they are applicable (rural flat terrain, urban flat terrain, complex terrain, coastal areas)

(viii) Level of sophistication: level 1 (screening models) and level 2 (refined models)

Whatever may be the classification criteria adopted for classifying the models, it is important to study the characteristics of the system.

(i) Size (local, regional, national, global), (ii) Time horizon (hour, day, month, year), (iii) Pollutant of concern (SO2, NOx, CO, SPM, photochemical oxidant etc.)
Atmospheric dispersion modelling is one of the large classes of phenomena, which include a deterministic part and a random element. The deterministic component may be modelled with all the precision allowed by the experimental input, whereas the random stochastic part is less precise or unpredictable. There are two extreme approaches to atmospheric modelling, the statistical and the analytical approach. The statistical technique, in its extreme form, looks into pure time series, whereas in analytical approach, an attempt is made to understand the physical process and to establish cause - effect relationship, which facilitates the final outcome. However, almost none of these ideal approaches are available/applicable directly in their present theoretical form. Most statistical models include some explaining variables, whereas most would be ‘pure’ analytical models requiring some statistical smoothening of input (Sharma, 2004).

The most important and popular way of classifying air pollution models is based on the model structure and the approach used for the closure of the turbulent diffusion equation which is widely used in urban air pollution modelling (Sharma and Khare, 2001).

The basic problem with all modelling studies in air pollution is the identification of the function ‘F’ that would allow the prediction of the concentration of the pollutant C (x, t) at any point in space x, and time t, if the emissions and other meteorological variables are given. Three different approaches have been established to identify ‘F’

(i) Deterministic mathematical modelling (analytical and numerical models),
(ii) Statistical modeling,
(iii) Physical modelling

The air quality model classification system is presented in figure 2.6 as described by Aggrawal, A. (2011).
Figure 2.6: Schematic Presentation of Air Quality Model Classification System

Source: Aggrawal, A (2011)
2.3.1 Deterministic Mathematical Models:

The deterministic mathematical models (DMM) calculate the pollutant concentrations from emission inventory and meteorological variables according to the solutions of various equations that represent the relevant physical processes. In other words, the differential equation is developed by relating the rate of change of pollutant concentration to an average wind and turbulent diffusion which, in turn, is derived from the mass conservation principle. The common Gaussian line source model (LSM) is based on the superposition principle, namely concentration at a receptor, which is the sum of concentrations from all the infinitesimal point sources making up a line source. This mechanism of diffusion from each point source is assumed to be independent of the presence of other point sources. The other assumption considered in DMM is the emission from a point source spreading in the atmosphere in the form of the plume, whose concentration profile is generally Gaussian in both horizontal and vertical directions. The deterministic model includes analytical model and numerical model. Both analytical and numerical models are based on the mathematical abstraction of fluid dynamics processes.

Limitation of deterministic model:

(i) Inadequate dispersion parameters, (ii) Inadequate treatment of dispersion upwind of the road, (iii) Requires a cumbersome numerical integration especially when the wind forms a small angle with the roadways, (iv) Gaussian based plume models perform poorly when wind speeds are less than 1m/s.

Deterministic mathematical models are further classified into two groups, Analytical and numerical models.

Analytical Models:

Analytical models provide solutions to the basic equations describing the process. In fact, most of the present analytical models for air quality
predictions are based on the Gaussian equation. These Gaussian models despite several limitations and assumptions have found favour with the scientific community, as they are very simple and include the solution to the simple Gaussian equation (Barratt, 2001). In addition to their user-friendly nature and simplicity, these models are conceptually appealing as they are consistent with the random nature of the turbulence of the atmosphere. Further, the development of Gaussian type dispersion equations/models has reached a level of sophistication such that they are routinely used as assessment tools by various regulatory agencies (USEPA, 2000). These simplified models can be applied with reasonable confidence to pollutant transport within unidirectional flows (e.g., over relatively flat terrains). However, they are less reliable for situations where the flows are more complicated. For example, flow over complex terrain or separated flows around obstructions and building wakes, where these Gaussian dispersion models cannot be applied (Hanna et al., 1982; Pasquill and Smith, 1983). The concentration of pollutants \( C \) at location \((x, y, z)\) from a continuous elevated point source with an effective height of \( H \) is given by following Gaussian dispersion equation (Turner, 1970) (Equation 2.3)

\[
C_{(x,y,z)} = \frac{q}{2\pi \sigma_y \sigma_z U} \exp \left( -\frac{1}{2} \left( \frac{y}{\sigma_y} \right)^2 \right) \left[ \exp \left( -\frac{1}{2} \left( \frac{z+H}{\sigma_z} \right)^2 \right) + \exp \left( -\frac{1}{2} \left( \frac{z-H}{\sigma_z} \right)^2 \right) \right]
\]

(2.3)

Where, \( \sigma_y \) and \( \sigma_z \) are horizontal and vertical dispersion parameters, determined as a function of stability class and distance from the source. \( U \) is the mean wind speed, \( Q \) is the uniform rate of release of pollutants and \( H \) is the effective plume height. For a continuously emitting infinite line source at ground level when wind direction is normal to the line source, the equation (2.3) reduces to (2.4).

\[
C(x, z) = \frac{q}{\sqrt{2 \pi U} \sigma_x} \left\{ \exp \left( -\frac{1}{2} \left( \frac{x+h_0}{\sigma_x} \right)^2 \right) + \exp \left( -\frac{1}{2} \left( \frac{z-h_0}{\sigma_x} \right)^2 \right) \right\}
\]

(2.4)

For ground level sources \( H = h_0 \) (plume rise).
Most of the highway dispersion models used for the preliminary estimation for screening purpose retained the basic Gaussian dispersion approach but used modified vertical and horizontal dispersion curves to account for the effects of surface roughness, averaging time, 2.6 and vehicle induced turbulence (Gilbert, 1997; Sunil, 2008).

**Numerical Models:**

Numerical Models, over the past several years, have been increasingly used to solve the complicated dispersion problems such as dispersion of heavier than air boundary layer flow over complex terrain, studying gas diffusion in thermally stratified flows, dispersion of pollutants around structures/buildings and in regional and mesoscale dispersion modelling. In addition, various numerical models based upon Lagrangian trajectory and Eulerian grid models are increasingly used for the prediction of various secondary pollutants like ozone. The formation of ozone involves highly complex and nonlinear photochemical reactions between VOC’s and NOx. These models can handle, at least theoretically, non-stationary, non-homogeneous conditions along with complex configurations of spatial domains such as rough terrains. These numerical models require rigorous mathematical computations through computer software and as such cannot be conveniently used for screening purpose by regulatory agencies. Moreover, these models require large input data and larger computational capabilities (Sharma, 2004).

**2.3.2 Statistical Models:**

The statistical models calculate concentrations by statistical methods from meteorological and traffic parameters after an appropriate statistical relationship has been obtained empirically from measured concentrations. Regression, multiple regression, and time-series techniques are some key methods in statistical modelling. The time-series analysis techniques such as ‘Box–Jenkins models’ have been widely used to describe the dispersion of Vehicular Exhaust Emissions at the traffic intersection and at busy roads.
Various studies involving statistical techniques have been used to forecast real-time, short term as well as long-term pollutant concentrations and for their trend analysis. This has been done by mostly using long-term (sometimes short also) emission, meteorology, and pollution concentration data. This modelling technique has been employed to find concentrations of primary as well as highly complex secondary pollutants like ozone (Sharma, 2004).

There are some limitations of statistical model, which include, (i) Require long historical data sets and lack of physical interpretation, (ii) Regression modelling often underperforms when used to model non-linear systems, (iii) Time series modelling requires considerable knowledge in time series statistics i.e. Auto Correlation Function (ACF) and Partial Auto Correlation Function (PACF) to identify an appropriate air quality model, (iv) Statistical models are site specific

2.3.3 Physical Models:

Physical modelling comprises of simulating the region (topography and sources) and meteorological condition in a laboratory like the wind tunnel and studying the behaviour of pollutant in a medium. These types of models are found very useful for solving any specific air pollution problem, but not for general ambient air quality predictions (Seinfeld, 1980). This type of physical modelling carried out in the wind tunnel, in which atmospheric flows have been modelled with air as fluid medium, has also been referred to as fluid modelling by various researchers (Sharma, 2004). Some limitation of the Physical model, which include, (i) Major limitations of wind tunnel studies are construction and operational cost (ii) Simulation of real time air pollution dispersion is expensive (iii) Real time forecast is not possible.

Various researchers worked on different methodologies and techniques to improve the existing models for a better result. Most of these work directed towards incorporating wind speed correction, modifying the dispersion parameter, considering vehicular wake etc. Several models have been improved by incorporating different modified parameters like CALINE4
(4\textsuperscript{th} generation), Highway 4 etc. Several attempts have been made to validate these models with experiments and measurement of field data resulted in improvements of these model. (Aggrawal, A., 2011)

2.4 VEHICULAR POLLUTION MODELS

Some major air quality models, which are presently available in the literature for pollution prediction near roadways, are discussed and compared bellow:

2.4.1 Simple Infinite Line Source Model:

This model was developed by Hanna. Expression for point source at ground level is as follows (Hanna et al. 1982; Perrin, et al., 1990) (Equation 2.5)

\[
C_{\text{point}} = \frac{Q}{\pi \delta_y \delta_z} \exp \left( \frac{y^2}{2\delta_y \delta_z} \right) \exp \left( \frac{2z^2}{2\delta_z^2} \right) \tag{2.5}
\]

Where,

\( C_{\text{point}} = \) Concentration in g/m\(^3\) at the receptor point C
\( Q = \) Source strength in g/s.
\( U = \) Mean wind speed along x direction in m/s. (along the road)
\( \delta_y = \) Horizontal dispersion co-efficient in m. (perpendicular to road)
\( \delta_z = \) Vertical dispersion co-efficient in m.
\( Y = \) Crosswind distance in m.
\( Z = \) Receptor height in m.

The concentration due to line source can be calculated by integrating the above equation along y direction from \(-\infty\) to \(+\infty\). Assuming the line source is infinitely long and wind is perpendicular to the roadway (y – direction)) and the pollutants are transported along x direction and dispersed in the vertical direction (Z- direction) and the resultant equation is as follows: (Equation 2.6 & 2.7)

\[
C = \sqrt{\frac{2}{\pi}} \left( \frac{Q}{u \delta_z} \right) \exp \left( -\frac{Z^2}{2\delta_z^2} \right) \tag{2.6}
\]

If Oblique wind condition (\( \theta \)) is considered.
\[ C = \sqrt{\frac{2}{n}} \left( \frac{Q}{u \delta \sin \theta} \right) \exp \left( -\frac{z^2}{2\delta^2} \right) \]  

(2.7)

And

\[ \delta_z = a \left( \frac{x}{\sin \theta} \right)^q \]

Where,

- \( Q = \) line source strength in g/m/s 
- \( X = \) receptor distance from the centre of the line source in m. 
- \( a,q = \) Coefficient which depends on stability condition. 
- \( \Theta = \) Road wind angle in degree. 

This is valid for \( \Theta > 45^0 \)

---

**Figure 2.7: Line source Dispersion Model**

The condition of the line source be infinite line source does not introduce considerable errors as long as the finite road length is greater than
3δ_y in both directions from the receptor (Miller et al, 1978). Moreover, it is restricted to infinite length and given an error when the length is small. (Figure 2.7)

2.4.2 Finite Line Source Model:

This model was presented by Csanady (1972), to overcome the problems by infinite line source model from Gaussian plume for point sources. (Equation 2.8)

\[
C = \frac{Q}{\sqrt{2n\delta_uy}} \left( \frac{L/2 - y}{\delta_y\sqrt{2}} \right) + \left( \text{erf} \frac{L/2 + y}{\delta_y\sqrt{2}} \right)
\]

(2.8)

C= Concentration in g/m^3 at the point C
Q= Source strength in g/s
U= Mean wind speed in m/s
δ_y= Horizontal dispersion parameter
δ_z= Vertical dispersion parameter
L= Length of line source

The limitation of the model is that it is applicable only when wind angle is perpendicular to the road.

2.4.3 General Motor Model (GM Model):

GM model is developed by Chock (1978) is a simple line source model. Where Q is the emission rate per unit length, u is the effective cross wind speed plus correction factor, h is the height of emission plus the plume rise h_p, \( \rho \) and \( \rho_o \) are densities of the plume and ambient air, R is the plume width. It was developed in an attempt to remove the limitations of earlier models by incorporating wind speed correction (U_o) and by suggesting modified values for the vertical dispersion parameter, z, to take care of the induced effect of the mechanical turbulence generated by traffic flow. In this
model pollution concentration $C$ at a given point $(x, y)$ is expressed as (Nagandra and Khare, 2002) - (Equation 2.9)

$$C(x, y) = \frac{Q}{\sqrt{2u_a\sigma_z}} \left\{ \exp \left[ -\frac{1}{2} \left( \frac{x+h}{\sigma_z} \right)^2 \right] + \exp \left[ -\frac{1}{2} \left( \frac{x-h}{\sigma_z} \right)^2 \right] \right\}$$  \hspace{1cm} (2.9)

And $h_p = \left[ \frac{\left( Rg (\rho_o - \rho_a) \right)}{\alpha \rho_o u^2} \right]^{0.5}$

The limitation of the GM model is that because of the infinite line source assumption, the model is applicable to a situation where the upwind segment of the road (measured from the perpendicular line drawn from the receptor and the road) is at least three times the distance between the receptor and the road.

2.4.4 Standard Research Institute (SRI) Model:

This model was developed by Johnson at Stanford Research Institute (Johnson, et al., 1971) and is known as SRI model (Figure 2.8). When the wind is parallel to the street, it advects the pollutant down the street. When it crosses the street at an angle, a vortex or helical flow pattern is generated within the street with mixing velocities lower than the street and relatively higher on the downwind side. This result in lower pollutant levels on the windward model can account for the mechanical air movement caused by traffic and also work under calm condition. The cross street circulation is shown in figure 2.8.

The concentration on the leeward side ($C_L$) of the street is given by the equation (2.10):

$$C_L = K \frac{Q}{(u_r + 0.5) \left( x^2 + z^2 \right)^{1/2} + 2}$$  \hspace{1cm} (2.10)

The concentration on the windward side ($C_W$) is given by the equation (2.11).

$$C_W = K \frac{Q}{w(u_r + 0.5)}$$  \hspace{1cm} (2.11).
Where,

- $u_r$ is the wind speed at roof-top.
- $K$ is the diffusivity constant depending on the stability class.
- $W$ is the width of the traffic lane.

**Figure 2.8: Schematic of Cross Street Circulation between buildings**

When the wind is such that neither leeward nor a windward case is appropriate, an intermediate concentration ($C_i$) is found by averaging the result of above equations. (Equation 2.12)

$$C_1 = \frac{C_{L} + C_{W}}{2} \quad (2.12)$$

### 2.4.5 General Finite Line Source Model (GFLSM):

This model was developed by Luhar and Patil. The basic approach, to develop this model is the co-ordinate transformation (Luhar et al., 1989). It is assumed that there are two co-ordinates systems, one is wind co-ordinate system and other is line source co-ordinate system. Wind co-ordinate system is presented by $X_1$, $Y_1$, $Z_1$ and line source co-ordinate system is represented by $X$, $Y$, $Z$. as shown in figure 2.9.

The expression for GFLSM is given below: (Equation 2.13)
\[
C = \frac{Q}{2\sigma_z u_e \sqrt{2\pi n}} \left\{ \exp\left[ -\frac{1}{2} \left( \frac{Z-H}{\sigma_z} \right)^2 \right] + \exp\left( -\frac{1}{2} \left( \frac{Z+H}{\sigma_z} \right)^2 \right) \right\} B \]  \hspace{1cm} (2.13)

Where

\[ B = \left[ \text{erf}\left( \frac{\sin \theta (L/2 - y) - X \cos \theta}{\sigma_y \sqrt{2}} \right) + \text{erf}\left( \frac{\sin \theta (L/2 + y) + X \cos \theta}{\sigma_y \sqrt{2}} \right) \right] \]

Figure 2.9: General Finite Line Source Model Co-ordinate system

Where,

\[ u_e = u \sin \theta + u_0 \]

“\( u_0 \)” accounts for lateral dispersion and also concentration divergence, when wind speed approaches zero. (Calm condition) (Figure 2.8).

2.4.6 CAR- FMI Model:

An operational model developed for contaminants in air from a road by Harkonnen (Harkonnen, et al., 1995). Finnish Meteorological Institute has
been suggested CAR-FMI model for the dispersion of pollutant from a road. This model is based on the analytical solution of the Gaussian diffusion equation for a finite line source. The dispersion parameters are evaluated using stability data produced by meteorological pre processing model. The overall models include an emission model, treatment of the meteorological time series, a statistical analysis of the computed time series of concentration and a graphical window based user interface (Harkonen et al., 1995).

The chemical transformation is modelled by using discrete parcel method and it contains the basic of nitrogen oxides and ozone. In this method, the chemical reaction is assumed to proceed independently of dispersion process.

2.4.7 HIWAY Model:

The model is a Gaussian steady state model for predicting the concentration of nonreactive gases at point receptors, downwind of the road in a relatively simple terrain (Turner, 1970). Each line is modelled as a straight and continuous finite line source with uniform emission rate, stimulated by a series of point source integrated at the receptor. The latest version of the model is upgraded to HIWAY 4 where modified dispersion and aerodynamic drag factor to original model are incorporated (Marmur et al., 2003). The United State Environmental Protection Agency (US-EPA) approved HIWAY model.

2.4.8 CAL3QHC Model:

CAL3QHC is a hybrid model, which includes CALINE3 line source dispersion model and a traffic algorithm for estimating vehicular queue length at signalised intersection (USEPA, 1995). While CALINE3 is used to predict the concentration of pollutant near highways, CAL3QHC is used to predict the concentration of pollutants near traffic junctions where vehicles have to wait on a queue in idling conditions for signals. CAL3QHC enhances
CALINE3 by estimating queue length and by estimating the contribution of pollutants from both moving and idling.

2.4.9 California Line Source Model:

California Line Source Model Version 4 (CALINE4) is a fourth generation line source air quality model developed by California Department of Transportation (USEPA, 1998). This model is based on the Gaussian diffusion equation and employs a mixing zone concept to characterized pollutant dispersion over the roadway. This model divides individual highway links into a series of elements (figure 2.10) from which incremental concentration is computed and then adds all to get total concentration on a particular receptor location.

Figure 2.10: Element series used by CALINE4

![Element series used by CALINE4](image)
The receptor distance is measured along a perpendicular from the receptor to the highway centre line. The first element is formed at this point as a square with sides equal to the highway width.

The element resolution become less important with distance from the receptor, hence the element is made larger in this model to permit efficiency in computation. Each element is modelled as an “equivalent finite line source” (EFLS) positioned normal to the wind direction and centred in the element midpoint. A local x-y co-ordinate system aligned with the wind direction and originating at the element midpoint is defined for each element and is shown in the figure 2.11. The emission occurring within the element is modelled using the cross finite line source Gaussian equation.

The concentration due to source segment of length dy is (Equation 2.14)

\[
dc = \frac{qdy}{2\pi \sigma_y \sigma_z} \left\{ \exp \frac{-y^2}{2\sigma_y^2} \left[ \exp \frac{-(z-H)^2}{2\sigma_z^2} + \exp \frac{-(z+H)^2}{2\sigma_z^2} \right] \right\}
\]  

(2.14)
Where,

\( \sigma_y, \sigma_z \) are the dispersion coefficient in y and z direction in m.

U is the wind velocity at effective release height m/s.

q is the line source strength in \( \mu g/m/s \)

H is the effective source height in m.

dy is the source segment length in m.

dc is the concentration of the source segment dy at receptor \((x, y, z)\) in \( \mu g/m^3 \)

CALINE4 treats the region directly over the roadway as a zone of uniform emission and turbulence. This mixing zone is defined as the region over the travelled way plus 3 meters (approximately two vehicle widths) on either side. The additional width accounts for the initial horizontal dispersion imparted to the pollutant by the vehicle wake.

In CALINE4, 'Discrete Parcel Method' is used to model \( NO_2 \) concentration. The discrete parcels are dispersed across the finite line source plume in accordance with the Gaussian methodology. The reactions take place within the parcels at the rates governed by the initial mixing zone concentrations and independent of the dispersion mechanism.

CALINE4 contains a method by which suspended particulates can be predicted. This procedure was developed by Ermak in 1989, is fully compatible with the Gaussian formulation of CALINE4. (CALINE4, 1989)

2.5 COMPARISON OF VEHICULAR POLLUTION MODELS:

Table 2.9 shows comparisons of various vehicular pollution models. Major Characteristics like dispersion parameter, plume rise, chemical reactions of pollutants, and dispersion of particles are considered for comparison.
### Table 2.9: Comparisons of Vehicular Pollution Models.

<table>
<thead>
<tr>
<th>Name of the Model</th>
<th>Dispersion parameter</th>
<th>Plume rise</th>
<th>Chemical reactions</th>
<th>Dispersion of particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple infinite line source</td>
<td>Ambient turbulence</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Finite line source</td>
<td>Ambient turbulence</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>GM</td>
<td>Traffic induced and ambient turbulence</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>SRI</td>
<td>Traffic induced due to building obstruction</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>GFLSM</td>
<td>Traffic induced and ambient turbulence</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>CALINE3</td>
<td>Traffic induced and ambient turbulence</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>CAL3QHC</td>
<td>Traffic induced and ambient turbulence</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>CAR-FMI</td>
<td>Traffic induced and ambient turbulence</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>CALINE4</td>
<td>Traffic induced and ambient turbulence</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>HIWAY-4</td>
<td>Ambient turbulence and aerodynamic drag factor due to traffic wake.</td>
<td>NO</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Various Gaussian based line source models are routinely used in India for carrying out vehicular pollution predictions along highways and roads and they generally require various input parameters pertaining to meteorology, traffic, the road geometry, land use pattern, besides receptor location. Besides the basic Gaussian dispersion approach, each dispersion model differs with respect to the treatment of modified wind and turbulence due to vehicle wakes near roads (Sharma, et al., 2013). The accuracy and precision expected of any air quality model depend on its intended purpose (fitness for purpose). Moreover, modelled concentrations cannot be expected to match observed concentration exactly, even for matching...
averaging time due to various simplifying assumptions and inherent uncertainties involved in modelling. Unfortunately, standard evaluation procedure, as well as performance standards accepted universally still do not exist (Barratt, 2001).

2.6 Comparisons of Experimental and theoretical observations:

Several researchers compared values of experimentally observed major air pollutant concentration with the predicted data for the pollutants concentration estimating using CALINE4 model. Bluett, et al., in (2005), has compared the measured and predicted values of CO concentration in Auckland, New Zealand. The comparison shows satisfactory results. Broderick, et al., (2005) has also made similar studies in Ireland and found that predicted concentration is ± 50% of monitored concentration. In India in Mysore city, Prakash, et al., (2015) made an experimental observation and theoretical predictions of the concentration of air pollutants. They have compared the measured and predicted values of SO$_2$, NO$_x$, and PM$_{2.5}$. The study found that the CALINE4 over predict PM$_{10}$ values in comparison to monitored data and under predicts NO$_x$ concentration.

2.7 Concluding Remarks:

From the literature review, it is observed that vehicular traffic is a major source of air pollution. The primary source of vehicular emission is the exhaust gases. It is observed that emission inventories are estimated, for different places including some places of India, by different researchers. However such studies have not been found for the state of Assam. Therefore, there exists a necessity for the assessment of emission inventory for the state of Assam. Moreover, emissions from different types of vehicles have not estimated for the state of Assam.

It is also observed that various models are proposed for the prediction of vehicular pollution concentration by different researchers. From the comparison made in the literature review, it is seen that the CALINE4 model will be the appropriate model to be used for the present work.
Comparisons between experimentally observed data and predictions using models have been reported by different researchers for different parts of the world including our country. However, such studies are not found in literature along the road segment of NH-37 passing through Kaziranga National Park. It is also observed from the literature review that the probable change in vehicular pollutant concentration in the (same road segment) NH-37 passing through Kaziranga National Park due to the probable increase in road traffic volume have not been studied. Therefore, it is worthwhile to undertake such a study along the road segment of NH-37 passing through Kaziranga National Park.