MATERIALS AND METHODS
The present study entitled “Studies on Monitoring and Assessment of Road Traffic Noise in Urban and Industrial Areas” was carried out in the city of Hyderabad capital of Telangana state, India. It was designed to assess the equivalent noise levels $L_{eq}$ and noise indices such as $L_{10}$, $L_{50}$ and $L_{90}$ for different environmental backdrops like residential area, mixed (commercial and residential) area, commercial and industrial areas of Hyderabad city.

The methodology used for all study locations consisted of

a) Monitoring and assessment of equivalent noise levels ($L_{eq}$) and noise indices $L_{10}$, $L_{50}$ and $L_{90}$ at different environmental settings of Hyderabad city i.e. residential, commercial and industrial areas.

b) Estimation and assessment of noise parameters i.e. Traffic Noise Index (TNI), Noise Climate (NC) and Noise Pollution Level ($L_{np}$) for all the study locations.

c) Measurement of hourly traffic volume of two wheelers, three wheelers and four wheelers (light & heavy); along with measurement of noise equivalent levels ($L_{eq}$) for each study location on diurnal basis.

d) Development of a road traffic noise prediction model based on the percentage of heavy vehicles and regression analysis to predict noise equivalent levels ($L_{eq}$) using Calixto model.

### 3.1 STUDY AREAS

Hyderabad which is the common capital city of the Indian states of Telangana and Andhra Pradesh in South India as per Andhra Pradesh Reorganization Act, 2014, that is scheduled to last for a maximum of ten years. Hyderabad occupies 650 square kilometers (250 sq mi), by the side of the banks of the Musi River, and has a total metropolitan population of about 7.75 million, which is fourth populous city out of all cities in India and making it sixth most densely, inhabited urban agglomeration.

The map of India showing Telangana state and Hyderabad along with the study locations such as Marredpally, Trimulgherry, Begumpet and Jeedimetla are identified is shown in Figure 3.1. These locations are further classified as Residential, Mixed (Commercial and Residential), Commercial and Industrial areas.
Fig 3.1: Location map of Hyderabad showing study locations (areas)

**Study Locations**
- Marredpally
- Trimulgherry
- Begumpet
- Jeedimetla
The classification along with the permissible limits of noise levels for different areas prescribed by CPBC are given in below table 3.1.

**Table 3.1: Ambient noise Quality Standards in respect of Noise given by CPCB**

<table>
<thead>
<tr>
<th>Area Code</th>
<th>Category of Area/Zone</th>
<th>L$_{eq}$ dB (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Day time (6 a.m. – 10 p.m.)</td>
</tr>
<tr>
<td>(A)</td>
<td>Industrial area</td>
<td>75</td>
</tr>
<tr>
<td>(B)</td>
<td>Commercial area</td>
<td>65</td>
</tr>
<tr>
<td>(C)</td>
<td>Residential area</td>
<td>55</td>
</tr>
<tr>
<td>(D)</td>
<td>Silence Zone</td>
<td>50</td>
</tr>
</tbody>
</table>

1. Day time shall mean from 6.00 a.m. to 10.00 p.m.
2. Night time shall mean from 10.00 p.m. to 6.00 a.m.
3. Silence zone is defined as an area comprising not less than 100 meters around hospitals, educational institutions and courts.

### 3.1.1 Marredpally

Marredpally lies to the north of Hyderabad primarily a residential area comprising a number of residential localities like Syndicate Bank colony and SBH colony along with many apartments. Mahendra Hills locality was developed during late 1990s. It has many busy centers and this region has many super markets with a lot of city hustle and bustle. One of the important places in this area is Institute of Printing Technology. One of the popular religious sites is St. Mary’s Church.

### 3.1.2 Trimulgherry

Trimulgherry is a main community that lies to the north of Hyderabad. It consists of residential areas (townships) which has popular localities like Gandhi Nagar and Vivekanadapuram. Along with this residential area it has some commercial activity in it because a lot of garment factories and super bazaars. One of the important religious places here are Sri Surya Bhagwan and Saibaba temple. A military hospital is located in this area.
region. The adjacent suburbs to this area are Karkhana and AOC. Some historical buildings are seen in this area which was built during the period of British era like an old British Jail. Sir Ronald Institute of Parasitology is where Sir Ronald Ross carried out his experiments and discovered the cure for Malaria.

3.1.3 Begumpet

The study location of Begumpet in its outlook is quite an urban center of Hyderabad. It connects to major parts of city like IT hub and other important places of the city because it is said to be the border place of Hyderabad and Secunderabad. Commercial activities have expanded to a very great extent due to increase in shopping malls, educational institutions, medical centers, government establishments and many private enterprises. The airport here which was earlier a major airport of Hyderabad but now it is used only by VIPs.

3.1.4 Jeedimetla

Jeedimetla is an industrial area which is located to the north west of Hyderabad city. As, the name suggests, it is popular for both small and large scale industries which is further alienated into small localities attributing different manufacturing blocks. Pharmaceutical industries are more here along with it there are other important industries like textiles, electrical and chemical. It serves as the most industrialized areas and has some small shopping centers and hospitals.
3.2 STUDY APPROACH:

The study at different areas is done by counting the number of vehicles (2 wheelers, 3 wheelers, 4 wheelers light and heavy vehicles) along with continuous measurement of equivalent noise levels ($L_{eq}$) and then predicting the noise levels by a model (Calixto).
3.3. ROAD TRAFFIC NOISE MONITORING

Noise descriptors are normally used to calculate sound pressure levels. They are represented as $L_{\text{min}}$, $L_{\text{max}}$, $L_{\text{eq}}$, $L_{10}$, $L_{50}$, $L_{90}$, $L_{\text{np}}$ (Noise Pollution Level), TNI (Traffic Noise Index), NC (Noise Climate), day and night averages, morning and evening peak hours. Marredpally (Residential), Trimulgherry (Commercial & Residential (Mixed)) Begumpet (Commercial) and Jeedimetla (Industrial) were selected as study locations of Hyderabad. Hourly count of two wheelers, three wheelers, four wheelers light and heavy vehicles were simultaneously carried out along with equivalent noise level $L_{\text{eq}}$ measurement for all study locations. The monthly averaged data is further classified into different quarters i.e. Quarter-1 (November 2010-February 2011), Quarter-2 (March-June 2011) and Quarter-3 (July-October 2011).

3.4. METHODOLOGY

3.4.1 Sound Level Meter

A sound level meter is a fundamental requirement for measuring the noise levels. It is designed to estimate the sensitivity level of loudness for the human ear and gives the desired, reproducible measurements for the sound pressure level. To determine the frequency range, spectral weighting of sound, along with the function of time constants, and computation of the equivalent continuous level the sound level meter does more complex work. The block diagram of sound level meter is shown in Figure 3.2 which consists of a microphone which acts as a transducer to convert the sound into its equivalent electrical signal. The magnitude of the electrical signal is small which comes out of the microphone and then this low electrical signal is amplified by a pre amplifier and output of which is connected to a frequency weighting network “A” or “C” and the output of filter is again amplified and is then given to an microcontroller which has an analog to digital converter which converts the analog signal to digital and then the output is given to a averaging system for data storage facility and then we have display unit which displays the desired noise levels in digital.
In the present study an Environmental sound level meter 2001(DL03) of Baseline Technologies is used. It is used to measure the existing noise equivalent level ($L_{eq}$) dB (A) at the various intersections (locations). The battery operated instrument has a microphone, amplifier “A” weighting network and an indicating meter which gives a reading in dB relative to $2 \times 10^{-5}$ N/m$^2$. The reading range is divided into three limits 0-50 dB, 50-100 dB and 100-150 dB. The display is alphanumeric type. We have used this instrument according to given standard conditions.

**3.4.2. Methods**

The steady traffic volume and equivalent noise levels $L_{eq}$ were measured at different locations of Hyderabad are taken diurnal (6:00am - 5:00am). Each study area covered a total of three sampling locations which are about one kilometer distance for three different days of a month and a total of 36 hours measurement was done at each study location for a period of one year (Nov 2010- Oct 2011). For every hour duration sixty measurements were made (i.e. at one minute interval) thrice for each month over a period of one year (Nov 2010- Oct 2011). The monthly averaged data is further classified into different quarters i.e. Quarter-1 (November 2010-February 2011), Quarter-2 (March-June 2011) and Quarter-3 (July-October 2011). The noise levels measured followed standard procedure by using a calibrated sound level (dB) meter during Nov 2010- Oct 2011 by keeping the sound level meter on a tripod almost to chest level (1.2m) in order to reduce errors due to reflection of sound from the body of investigator and the instrument was kept at 5m away from the roadside. The noise monitoring was done on working days excluding Sunday and local holidays in good climatic conditions in order to get consistent results. The individual and total vehicle count and $L_{eq}$ were correlated and regression equations were interpreted. The total number of vehicles (traffic volume (Q)) and the

![Fig 3.2: Block diagram of sound level meter](image-url)
percentage of heavy vehicles contribute to the total traffic \( (\text{traffic mix ratio (P)}) \). Comparison was made between the observed and calculated equivalent noise levels \( L_{eq} \) (using Calixto model).

3.4.3. Noise Descriptors

Noise descriptors such as \( L_{eq}, L_{10}, L_{50}, L_{90}, \text{TNI (Traffic Noise Index)}, L_{np} \) (Noise Pollution Level), \( \text{NC (Noise Climate)}, L_{dn}, L_{den}, Q \) (Traffic volume) and \( P \) (Percentage of heavy vehicles) are assessed to reveal the amount of noise pollution created due to heavy traffic in these studied locations.

3.4.4 Traffic Density Measurements

The noise levels are directly proportionate to traffic density. In the present study, the traffic density at each junction was determined on 24hr basis i.e., from (6:00am – 5:00am). By counting the number of vehicles passing through a particular point on either side of the road, the traffic volume was evaluated. Apart from counting two wheelers like scooters, motorcycles, three wheelers like auto_rikshaws, four wheeler light vehicles like cars and heavy vehicles such as buses and trucks at all study locations and equivalent noise levels \( L_{eq} \) were also recorded for each hour simultaneously.

3.5 MEASUREMENT OF NOISE LEVELS

3.5.1 Equivalent Noise Levels \((L_{eq})\)

Equivalent continuous (A-weighted) sound level is defined as the steady sound level which has the same amount of acoustic energy as the fluctuating level for a prescribed period of time. One hour \((L_{1h})\), 24 hours \((L_{24h})\), and the day time hours \((6 \text{ a.m. to 10 p.m.}) \) \((L_d)\), and the night time hours \((10 \text{ p.m. to 6 a.m.}) \) \((L_n)\) are the commonly prescribed time periods.
The definition of $L_{eq}$:

$$L_{eq} = \left[ \frac{1}{T} \int_0^T \frac{P^2(t)}{P_0(t)^2} \right]$$

Where $T=\text{Total measurement time}$; $P(t)=\text{A-weighted instantaneous acoustic pressure}$

$P_0=\text{Reference acoustic pressure}=20\mu\text{Pa}$

For a period of time, the sound energy is expressed in terms of quality called $L_{eq}$ in the environment which is the equivalent continuous noise level. It is equal to the total energy emitted during that period if it is maintained continuously. It is the mean rate at which energy is obtained by the human ear during the period mentioned and is expressed in dB (A). $L_{eq}$ has a good measure of intensity and gives more emphasis on occasional high noise levels, which can be quite disturbing. $L_{eq}$ can be applied to any variable (fluctuating) noise level. Mathematically it is a constant noise level which has the same amount of energy as the fluctuating level for a given time. It is directly related to the mathematical integration of the square sound pressure when written as a mathematical expression it is:

$$L_{eq} = 10\log_{10} \left[ 10 \sum_{i=1}^{i=n} \frac{L_i}{10} \right]$$

Where $N=\text{the total number of samples taken}$

$L_i=\text{the noise level in dB (A) of i-th sample.}$

This expression is used for calculating $L_{eq}$ value for every hour at each study location.

For calculating $L_{eq}$ per day at each study location the formula used is,

$$L_{eq} = 10\log_{10} \left[ \sum_{i=N}^{i=n} fi10^{i10} \right]$$

Where, $fi=\text{fraction of time}$

$N=\text{Total number of samples taken}$.
3.5.2 Noise Index Levels

For noise levels, it is possible to illustrate some important features of noise using statistical quantities for a given period of time interval. By means of the percent of time, certain noise levels exceed the time interval it is calculated. The notation for the statistical quantities of noise levels is described below.

By integrating sound level meter, hourly $L_{eq}$ values have been computed and measured in dB (A).

The sound level that has been exceeded “X” percent of time in a measurement period is defined in this way. The value of the sound level history over a given period of time is presented in the form of a cumulative distribution. $L_{10}$, $L_{50}$ and $L_{90}$ (Rao and Rao, 1992 and 1991; Peterson, 1980) are the most commonly used percentile exceeded sound levels.

- $L_{10}$: The levels which exceeded throughout 10% of the measuring time in dB (A), i.e. 10 percentile exceeded sound level (average peak level).
- $L_{50}$: The levels which exceeded for the duration of 50% of the measuring time in dB (A), i.e. 50 percentile or median value of sound level).
- $L_{90}$: The levels which exceeded all through 90% of the measuring time in dB (A), i.e. 90 percentile exceeded sound level (average background level).
- $L_{day}$: As per the guidelines of CPCB the day time limit is between 06.00 hrs to 22.00 hrs as outlined in ministry of environment and forest notification So 123(E) dated 14/02/2000.
- $L_{night}$: As per the guidelines of CPCB night time limit is between 22.00 hrs to 06.00 hrs as outlined in ministry of environment and forest notification So 123(E) dated 14/02/2000.

3.5.3 Diurnal Variations of Noise Levels

3.5.3.1 Day and night average sound level $L_{dn}$:

$L_{dn}$ is a complex long term $L_{eq}$ values for day and night (termed $L_{day}$, and $L_{night}$) and an indicator. $L$ represents “level”, $d$ represents “day” and $n$ represents “night”. They are estimated by the subsequent formula. It is also same for a 24hrs equivalent sound level except for that an additional 10 dB (A) weighing penalty is added to the
instantaneous sound level before computing the 24hrs average during night time period (22:00 to 06:00 hrs).

\[ L_{dn} = 10^{10 \log \frac{16 \cdot 10^{\frac{L_{\text{day}}}{10}} + 8 \cdot 10^{\frac{L_{\text{night}+10}}{10}}}{24}} \]

\( L_{dn} \) defines its time periods as follows:

- **day**: 6:00 to 22:00 hrs.
- **night**: 22:00 to 6:00 hrs.

### 3.5.3.2 Day, evening and night average sound level \( L_{\text{den}} \):

\( L_{\text{den}} \) specifies a complex long term \( L_{\text{eq}} \) values for day, evening and night (\( L_{\text{day}} \), \( L_{\text{evening}} \) and \( L_{\text{night}} \)). Where \( L \) represents “level”, \( d \) represents day, \( e \) represents “day” and \( n \) represents “night”. \( L_{\text{den}} \) (day, evening and night) noise value is calculated by the subsequent formula. It is similar to the above formula except an additional 5 dB (A) is added to the instantaneous sound level before computing the 24hrs average during evening time period (19:00 to 22:00 hrs).

\[ L_{\text{den}} = 10^{10 \log \frac{12 \cdot 10^{\frac{L_{\text{day}}}{10}} + 4 \cdot 10^{\frac{L_{\text{evening}+5}}{10}} + 8 \cdot 10^{\frac{L_{\text{night}+10}}{10}}}{24}} \]

\( L_{\text{den}} \) defines its time periods as follows:

- **day**: 6:00 to 19:00 hrs
- **evening**: 19:00 to 22:00 hrs
- **night**: 22:00 to 6:00 hrs

### 3.6 IMPACT OF VARIOUS PARAMETERS ON NOISE LEVELS

#### 3.6.1 Traffic Noise Index (TNI)

To describe community noise, Traffic Noise Index (TNI) is used. The amount of variability in observed sound levels is taken into consideration by TNI. In order to improve the correlation between traffic noise measurements and subjective response to noise a pursuit is made by TNI and was proposed by Griffiths and Langdon in 1968.
In order to estimate the annoyance response due to traffic noise the TNI values were enumerated and the Value of TNI over 74 dB (A) (Scholes and Sargent, 1971, Ma et al., 2006) is defined as the threshold of over criterion and the traffic noise index is defined by

\[ \text{TNI} = 4 \left( L_{10} - L_{90} \right) + L_{90} - 30 \text{ dB (A)} \]

Where, \( L_{10} \) = 10 percentile exceeded sound level
\( L_{90} \) = 90 percentile exceeded sound level

All these are in dB and measured during 24 hours period.

### 3.6.2 Noise Pollution Level (\( L_{np} \))

At times to describe community noise, which employs the equivalent continuous (A-weighted) sound level and the magnitude of the time fluctuations in levels Noise Pollution Level (\( L_{np} \)) is used. \( L_{np} \) was developed by Robinson in the late 60’s (Schultz, 1972) and has a threshold value of 72 dB (A) (Scholes and Sargent, 1971).

\[ L_{np} = L_{50} + \frac{\left( L_{10} - L_{90} \right)^2}{60} + (L_{10} - L_{90}) \]

### 3.6.3 Noise Climate (NC)

Sound levels will be fluctuating over an interval of time and is assessed by the following formula. The range over which the fluctuations occur is known as Noise Climate (NC).

\[ \text{NC} = (L_{10} - L_{90}) \]

Where, \( L_{10} \) = 10 percentile exceeded sound level and \( L_{90} \) = 90 percentile exceeded sound level or background noise level which is present due to absence of traffic vehicular movement at the time of record.


3.6.4 Traffic Volume \((Q)\)

The level of noise varies directly proportional to the no. of vehicles on a road (Fisk, 1975). Traffic volume is the total number of vehicles streaming on a road per hour.

3.6.5 Percentage of Heavy Vehicles \((P)\)

The volume heavy vehicle consists of buses and trucks is called truck traffic mix ratio and the noise generated by them will be high when compared to light vehicles. It is oblivious that increase in number of heavy vehicles is an important factor for creating annoyance. This is particularly the case in the shift in the range between continuous noise and “just annoying noise events” (Stallen, 1999; Gjestland, 1987; Schultz, 1977; Scholes and Sargent, 1971). Noise levels increase is observed with this ratio.

3.6.6 Speed of Vehicle \((V)\)

If the vehicle is traveling within a range of limited speed, the noise produced is independent of speed and depends on the type of vehicle. Vehicle speed is taken as an average speed of all vehicles whose speed ranges between 20-50 km/hr.

3.6.7 Road Conditions

One of the main reasons for increase in traffic noise pollution is condition of roads. Narrow roads, surface of the road and frequent road repair all lead to traffic congestion and thereby increasing noise.

3.7. TRAFFIC NOISE MODEL

A noise prediction model is required for predicting noise levels and helps in planning and design process creating a healthy noise free environment (Brown and Macdonald, 2003). To predict noise levels in a satisfactory a model needs to be developed using statistical information which should be simple and also data should be easily obtained. A statistical model is developed in which percentage of heavy vehicles play a significant role in increase of road traffic noise. Calixto model is used for road traffic noise in an urban setting (Calixto et al., 2003). We calculate a weighting factor \((n)\) which is varying from 4 to 10 gives the weightage of presence of heavy vehicle in road traffic.
noise emission for Indian road conditions in our present study the weighing factor (n) is taken as 9.5. The validation of the above developed model (Calixto) is then verified for validation by $R^2$ value and then found appropriate for Indian road conditions. Regression equations were also found between vehicles and observed $L_{eq}$. A set of regression equations were found between the observed and calculated $L_{eq}$ for all study locations and a value of $R^2$ was found.

### 3.7.1 Calixto Model:

The total sum of vehicles is always the combination of light vehicles which comprises of motorcycles, scooters, auto_rikshaws and cars and heavy vehicles. A heavy vehicle produces more sound when compared to light vehicle when it passes on the road during a certain time interval under speed considerations a model is developed to predict/calculate equivalent noise levels for Indian road conditions. Calixto model is best suited model for Indian roads, in this survey, a factor, n, has been considered for such vehicles, so that an equivalent value could have been achieved for the traffic flow, $Q_{eq}$. By considering $Q$ as the real hourly vehicle flow, $VP$ as the percentage of heavy vehicles and n as the weighting factor, we get:

$$Q_{eq} = Q \times (1 + n \times VP/100)$$  

So, the term $10 \text{ log } (Q_{eq})$ will be transformed into $10 \text{ log } [Q(1+n\times VP/100)]$. The factor value, n, will have to have a certain value that results in the largest correlation coefficients between the noise levels and this factor $10 \text{ log } [Q(1+n\times VP/100)]$. By varying the factor from 4 to 10, the largest correlation coefficients between $L_{eq}$ and the above term

Mathematically, the curve can be represented by:

$$Y= a \times x + k \quad (2)$$

By applying the variables on the straight line equation, we get:

$$L_{eq} = a \times 10 \text{ log } [Q \times (1+n\times VP/100)] + k \quad (3)$$
Where ‘n’ is the weighting factor and the values of constants ‘a’ and ‘k’ can be found after the statistical methods of linear regression.

3.8 STATISTICAL ANALYSIS

Results obtained were analyzed statistically wherever necessary. The ambient noise levels data involving equivalent noise levels ($L_{eq}$) along with different noise indices and parameters averages were subjected for analysis to estimate the means (monthly, quarterly and annual) for each study location along with this standard deviation and interval estimates at 95% confidence levels. Relationship between two variables is determined by correlation and regression technique. ANOVA technique was used to understand the difference within and between the sites. Microsoft Excel tools were used to carry out the statistical analysis.
Plate 1: Noise level measurements at the study location of Marredpally

Plate 2: Noise level measurements at the study location of Trimulgherry
Plate 3: Noise level measurements at the study location of Begumpet

Plate 4: Noise level measurements at the study location of Jeedimetla