Assessment of Noise Quality of Kolkata Metro Railway System- A Case Study

(A thesis submitted in partial fulfillment of the requirements for the award of degree of Master of Civil Engineering in the Faculty of Engineering & Technology of Jadavpur University)

Submitted
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Contents

List of Tables

List of Figures

Chapter -1

Introduction

Noise is a term which is come from the word *"nausea"*, that means unwanted sound. The environment surrounding us is getting affected by various forms of pollution. Among them noise pollution is considered to be a major one. Noise is originated from various sources, transmitted by a medium (usually air), which finally makes annoyance and other impacts on receptors. Noise is generated by human activities, especially from the urban areas and development of transport and industry. Not only urban population but also small villages and industries are exposed to this noise pollution problem. Nowadays noise related problem is a major environmental issue even in developed countries.

Noise sources can be broadly classified in the following three categories–

- **Industrial Noise Sources**
- **Traffic Noise Sources**
- **Community Noise Sources**

Out of these three noise sources, traffic related noise source contribute most of the noise related pollution problem in our environment. In the sphere of traffic noise, 70% of the related problems are contributed by vehicular traffic sources.

Nowadays, in India, the number of vehicles is increasing gradually. Nearly 2/3rd of the total noise pollution in an Indian metropolitan city is related to this traffic noise pollution *(Tandel et al., 2011).* There is enormous impact of road traffic noise on quality of life of a human being and property values close to any highway or traffic dense road in the sphere of urban environment. However, we can reduce its magnitude to some extent by introducing noise barrier or enclosures. The noise coming from Mass Rapid Transit System (MRTS) also induces some adverse impact on environment.

Various parts of rail produce different types of noise under moving or stationary condition (not in dead condition). Under moving condition noise is generated from rail-wheel interaction, whistle, some aerodynamic noise sources (viz. whooshing noise) particularly when the locomotive moves within a tubular structure. Other sources of noise are noise from visual and audio announcement, advertisement and warning system noise and to some extent noise from passengers.

Metro railway is now moving both underground and over-ground. In the case of over-ground metro railway, railway noises may be generated from the locomotive engines, noise coming from the wheels turning on the railroad track and some sorts of noise may come from outside activities. Train may also employ horns, whistles, bells, and other noisemaking devices for both communication and warning, trains gave forward by electric traction engines and controlled by high speed electronic inverters can produce a whining noise. Although, the Walter's studies *(Walter's D, 1989)* on annoyance from rail traffic noise in residential areas had suggested that the rail traffic is less annoying than road traffic noise, rail noise has some adverse impact on human beings. Noises from underground and over-ground metro railway can contribute to cardiovascular disease in humans and increased chances of coronary artery diseases. It decreases the working efficiency of a man, produces adverse effect on concentration of a man. It can affect pregnant woman and interfere with the sleep structure of human being. In animals, noise can increase the risk of death by altering predator or prey detection and avoidance, interfere with reproduction and navigation, and contribute to permanent hearing loss.

In the context of the aforesaid adverse impacts of railway noise, an assessment of noise quality in metro railway both underground and over-ground can be treated as an important task to be dealt with.

Chapter-2

Review of Literatures

2.1 General

Noise can be broadly classified depending upon the noise sources. It can be categorized into three classes viz.:

1) Transport Noise 2) Occupational Noise and **3) Neighbourhood Noise**

2.1.1 Transport Noise

Transport noise can be subdivided into following categories

a. Road traffic noise

Vehicles on roads act as a major noise sources than any other existing noise sources, which make serious impact on human being. Traffic related noise has been increasing continuously with the time because of the steady increase in the number of vehicular traffic, which in turn has increased the road traffic density. Traffic acts as a major source of noise. Noise volume is directly proportional to traffic speed. Modern highways and traffic systems deal with high speed. Road traffic noise depends on a number of operating factors of vehicles and also on the traffic densities and the hour of the day. There are distinct day peak and night peak of noise level on urban road, depending on the traffic density and rush of people movement to and from work. Heavy diesel trucks contribute more noise than other vehicles. There are different noise limits for different countries. In Indian scenario the limits imposed on noise production from various places as follows:

- ✓ For **industrial areas** it is **75 dB (day)** and **65 dB (night)**
- ✓ For **commercial areas** it is **65 dB (day)** and **55 dB (night)**
- ✓ For **residential areas** it is **50 dB (day)** and **45 dB (night)**
- ✓ For **sensitive areas** up to 100 m around hospitals, education institutions, courts etc. it is **50 dB (day)** and **40 dB (night)**.

However, these limits are violated in most of the times.

b. Aircraft noise

Aircraft noise is not a continuous noise, but it is intermittent. During take off and land aircraft engine produce extreme noise and it creates the peak noise level. The peak frequency varies with the number and type of aircraft as well as the operational height. For reducing aircraft noise level newly designed aircraft model has introduced. There is a trend among aircraft and engine manufacturers to produce quieter power units and airplanes.

c. Rail traffic noise

When compared with the other traffic related noise sources railway noise is less nuisance. Railway noise is generally of lower frequency than that of vehicular noise and furthermore, most railway tracks run through rural areas. Although, people residing in localities near railway tracks are exposed to noise nuisance, but still the effect is not as severe. Also, the introductions of diesel and all electric locomotives have greatly reduced rail traffic noise. However, with the introduction of urban metro railway system, especially while running overground, it has been felt to be generating noise interferences in the urban environment.

2.1.2 Occupational noise

This type of noise is mainly generated by industrial machines and thus it affects large numbers of people. Occupational noise comes from domestic gadgets like washing machines, vacuum cleaners etc. Industrial workers are victims of occupational noise and suffer from potential health hazards.

2.1.3 Neighbourhood noise

This includes different types of noise sources that annoying the general public like loud speakers, TV, radio, public functions etc, which causes noise nuisance to nearby residents.

2.2 History and brief summary of rail-road noise regulations in U.S

The Noise Control Act of 1972 marked noise as a growing danger and declared the policy of the United States to be to endorse a noise free environment for all Americans on an account to consider adverse health effect of noise. In the Act it was included that the authorization to establish federal noise emission standards for products distributed in commerce, and the mandate for the U. S. Environmental Protection Agency (EPA) to coordinate federal activities in noise control. In Section 17 of the Act specifically required the EPA to spread regulations setting limits on “noise emission coming from operation of the equipment and facilities of surface transporters engaged in interstate commerce by railroad.” Further it was required that such regulations include noise emission standards which "reflect the extent of noise reduction attainable through the application of the best available technology (BAT), taking into consider the cost of compliance."

In accordance with Section 17 of the Act, the EPA issued final railroad noise emission standards on December 31, 1975, which was applied to all railroad cars and locomotives, except steam locomotives. On August 23, 1977, the Federal Railroad Administration (FRA) issued Railroad Noise Emission Compliance regulations setting forth procedures for enforcing the EPA standards.

In June of 1977, the Association of American Railroads other several railroad companies, confronted the EPA regulation in the U. S. Court of Appeals on the basis that the regulation did not cover all. As per court order EPA issued noise regulations for additional railroad equipment and facilities in April 1979. Standards for overall railroad facility and equipment noise, as well as specific standards for retarders, refrigerator cars, and car coupling operations railroad equipment and facilities as required by the Noise Control Act was established as per these regulations. The concern of the railroad industry was that, lacking federal pre-emption of bodily railroad noise source regulations, a deviation of differing and inconsistent standards in all jurisdictions overall the railroad's routes may be developed. In debut, local communities would not approximately be bound by the protective "best available technology, taking into account the cost of compliance" passage of the Noise Control Act.

After a prolonged public comment period, on January 4, 1980, EPA published final guidelines, establishing standards for four specific noise sources, namely, locomotive load cell test stands, switcher locomotives, retarders, and car couplings. There was a property line standard, which deals with the total noise emitted from rail yard facilities comprising sources which are not covered by existing standards, was to be issued by EPA after further assessment of the extensive comments received. However, EPA did not proceed with the scheduled endorsement. Instead, on November 12, 1981, the parties to the AAR hearing filed with the court a "Status Report," declaring that the agency had concluded that no furthermore standards are inexorable to regulate rail facilities and equipment. It was concluded that the proposed standards are unnecessary; EPA withdrew both the suggested property line and refrigerator car standards. Parallel to the development of railroad noise standards by EPA, the FRA was developing guidelines of maximum permissible noise levels within locomotive cabs and railroad worker's residential quarters and safety standards setting minimum and maximum sound levels from audible warning devices (horns) on locomotives. Up to 1983, the Environmental Protection Agency (EPA) monitored all federal noise control activities through its Office of Noise Abatement and Control. However, Congress phased out the office's funding in FY1983 as part of a shift in federal noise control policy to transfer the primary responsibility of regulating noise to state and local government bodies. Although EPA no longer plays a main role in regulating noise, its past standards and regulations remain in effect, and other federal agencies, including the FRA, continue to establish noise standards for sources within their regulatory jurisdiction.

FRA had continued to use the EPA standards as the basis for compliance determination with respect to most areas of railroad noise. As a regulatory authority FRA published new regulations or edited existing noise standards for consideration of public safety and occupational health. The protocols which administered railroad noise emissions are summarized in **Table 2.1**. Compliance with these rules was determined by FRA inspectors, and sometimes by noise professionals working for railroad equipment manufacturers, or by the railroads themselves.

Table-2.1: **Regulations Governing Railroad Noise Emissions**

Agency	Code of Federal Regulations (CFR) Number	Title
EPA	40 CFR Part 201	Noise Emission Standards for Transportation Equipment Interstate Rail Carriers
FRA	49 CFR Part 210	Railroad Noise Emission Compliance Regulations
FRA	49 CFR Part 222	Use of Locomotive Horns at Public Highway-rail Grade Crossings
FRA	49 CFR Part 227	Occupational Noise Exposure
FRA	49 CFR Part 228	Hours of Service of Railroad Employees (Sleeping Quarters)
FRA	49 CFR Part 229	Railroad Locomotive Safety Standards (Locomotive Horns and Locomotive Cab Interior Noise)

(*Source: U.S. Department of Transportation, Federal Railroad Administration, Handbook for Railroad Noise Measurement and Analysis (2009*))

Line haul and yard operations: The noise generated from railroad line haul and yard operations were governed by two complimentary rules: 40 CFR Part 201 – Noise Emission Standards for Transportation Equipment; Interstate Rail Carriers and 49 CFR Part 210 - Railroad Noise Emission Compliance Regulations.

Railroad employee sleeping quarters: The noise environment in railroad employee sleeping quarters was controlled by the FRA, in 49 CFR Part 228 – Hours of Service of Railroad Employees. This rule established the maximum noise level which would be considered as the level permitting "an opportunity to rest."

This regulation was taken into consideration during the construction (or reconstruction) of railroad employee sleeping quarters on railroad property. This regulation was issued by the FRA on July 19, 1978, in concern with provisions of the Hours of Services Act (Public Law 91-169). This Act made it unlawful for any common carrier if there is no such noise controlling residential environment for workers, opportunity to take rest, free from interruptions caused by noise under the control of the railroad".

Locomotive cab noise: The noise environment in locomotive cabs was governed by a set of complimentary FRA regulations: 49 CFR Part 227 – Occupational Noise Exposure, published on February 26, 2007, and 49 CFR Part 229 – Railroad Locomotive Safety Standards (specifically, 49 CFR Part 229.121 and Appendix H to Part 229), both of which were first enacted in 1980.
This rule was based on the Occupational Safety and Heath Administration's (OSHA) occupational noise standard, with certain aspect amended to the unique circumstances of the railroad environment. It required railroads to fix limit on employee noise exposure level to an 8-hour time-weighted average (TWA) of 90 dB(A), to develop and implement a noise monitoring program and govern an effective hearing conservation program for those employees who were exposed to noise at or above an 8-hour TWA of 85 dB(A).

Locomotive horns (audible warning devices): The sounds from locomotive horns and other audible warning devices were regulated by 49 CFR Part 229 – Railroad Locomotive Safety Standards (specifically, 49 CFR Part 229.129), and 49 CFR Part 222 Use of Locomotive Horns at Public Highway-rail Grade Crossings. These rules established both minimum and maximum sound levels for locomotive and wayside horns; described the measurement instruments and test site requirements; and specify meteorological criteria, background noise criteria, sound level measurement procedures and record keeping procedures.
On June 24, 2005, the FRA published the final rule necessitating the use of locomotive horn sounding for trains approaching highway-railroad grade crossings (49 CFR Part 222 and 49 CFR 229.129). In addition to the minimum sound level requirement, this rule indicated a maximum sound level for railroad horns, 110 dB(A).

Noise Measurement Instruments

There were two types of instruments which could be used for measuring railroad noise data for regulatory compliance: either a sound level meter (SLM) or a dosimeter (a specialized type of sound level meter). **Those instruments actually consisted of three different parts**: a microphone, a preamplifier, and a measurement device, schematically represented in **Figure 2.1**. That instrument also required a windscreen to protect the microphone from wind effect, a sound level calibrator to check the accuracy of the components, and batteries to power the measurement device.

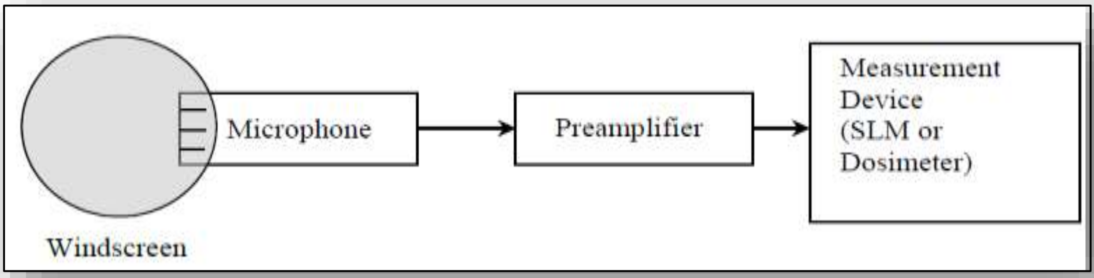


Fig-2.1: Typical Noise Measurement Instrument
(*Source: U.S. Department of Transportation, Federal Railroad Administration, Handbook for Railroad Noise Measurement and Analysis (2009*))

The sound level meters, dosimeters, and microphone components might experience periodic, comprehensive, laboratory calibration to verify and document their accuracy. Typically, those professional calibrations were performed annually; however, the manufacturer's instructions for each component should be checked for specific time intervals. A certificate of calibration from the National Institute of Standards and Technology (NIST) was provided to the user.

In the present study, the subject matter is related to railway noise, especially the noise from metro railway, which may underground or may be over-ground. On reviewing related literatures, different noise quality assessment works can be categorized in following three categories based upon the location of noise monitoring.

- Noise impact measurement in different areas of a city
- Noise impact measurement in metro railway platforms
- Noise impact measurement within metro railway rakes

2.3 Noise impact measurement in different areas of a city: Indian Scenario

2.3.1 Noise impact assessment of MRTS in Delhi city

Garg et al. conducted a noise impact assessment of mass rapid transit systems for Delhi city on April, 2011. In this study, noise and vibration assessment were considered as two fundamental elements of the EIA studies of mass transit projects. MRTS plays an important role for the development of Delhi transport facilities with the help of gradually technological inventions. To achieve complete

acceptability to the commuters, it is desired that their operation should not cause further noise and vibration problems. This study describes that international noise standard planned for the noise of transit trains and investigates the noise impact assessment of elevated metro rail corridor in Delhi. The cumulative accentuated ambient noise levels due to operation of elevated metro trains in areas based on their traffic density was analysed in this study.
This work investigated the increase in noise levels due to elevated metro rail corridor in different places in Delhi city. The assessment of sound exposure level was based on:

- **Long term measurement** (24 h) was carried out at some selected locations in both exposed and some protected areas.
- **Short term measurement** (1 h) was carried out in a number of favourable positions.

Measuring instrument

Noise quality measurement was conducted by a calibrated **Sound Level Analyzer Norsonic, Nor 118**,

Work methodology and observation of above study

A case study was conducted by applying **FTA (Federal Transit Administration)** criteria to evaluate effect of metro train noise along elevated metro rail corridor at certain location of peak traffic hours (hourly L_{eq}) is shown in **Table-2.2.**

Table-2.2: Measured day-time noise level along metro corridor

No.	Location	L_{eq} in dB(A)
1	Pusa Gate	78.8 ± 1.3
2	Link Road	73.7 ± 1.1
3	Patel Nagar	73.5 ± 2.0
4	Tilak Nagar	73.4 ± 1.0
5	Dwarka	64.3 ± 2.3
6	Jhandewalan	74.2 ± 2.4
7	Shaadipur	75.8 ± 2.7
8	Dwarka More	73.4 ± 1.8

(Source: Garg et al (2011))

In Delhi city for an average population density of 10,000 people per square mile, it was observed that the standard of 55 dB DNL exceeded at most of the metro

stations. However, at that time not many complaints had been reported related to the impacts of metro railway noise on living style of inhabitants. It was also observed that vehicular noise is verily responsible for enhancement of ambient noise level. Radiation of sound spectrum from metro rakes on elevated track was at 5m distance from the source.
Noise measurements were carried out by a sound level meter which was installed on a pneumatic platform moved on either side of the track and in level with the elevated corridor viaduct wall parapet.

Study on elevated metro corridor

Noise levels determined for the metro trains at maximum speed condition and at a distance of 5 m from track was **75±2.3 dB(A)** in at-grade and elevated corridor.

Study on underground metro corridor

In the case of underground station (e.g. **Vidhan Sabha**) it was increased by **10 dB(A)** due to reverberant sound field. The measured braking noise was **85.4 ± 1.5 dB(A)** in elevated track and L_{max} for the train starting from the elevated track was **78.5 ± 1.0 dB(A)**. The measured total at-grade noise of metro at a distance of 15 m was **69 ± 4.7 dB(A)**.

Noise study in Pusa Road (outside the metro corridor)

Noise study in **Pusa Road** from various distances of metro corridor suggests that the noise exposure decreased with increasing distances from metro track due to relatively high traffic density beneath the track. It was difficult to distinguish metro train noise and traffic noise, although the passage of train was perceptible while standing beneath the track due to the structural noise radiated by the track elements and pillars.

Considering both day and night L_{eq} values and depending upon the operational frequency of the metro trains, a noise impact assessment exercise was made. Similar analysis was carried out at **Tis Hazari** metro station.

2.4 Noise impact measurement in different areas of a city: Abroad scenario

2.4.1 Railway Noise measurement in France

In another study conducted by *Maurin M. (1977)*, a national survey was made in **France** during **1977** on environmental nuisances due to all forms of transport.

From the numerous data, it was possible to find out results with reference to the impact of railway noise, partly from results of questionnaire survey and rest from results of acoustical measurements. In several towns, there were questionnaire survey and acoustical measurement was conducted. In this case rail and air transport noise nuisance effects appeared to be of relative importance, with that of road transport very much larger than either.

Methodology of the study

Noise monitoring was conducted between **21:00** and **22:00** hours at the front face of a quarter of the buildings **(305 recordings).** There were combine noise effect of trains and from other sources was observed. The operators were made notes of all events resulting in noise during the entire measurement period of the recordings, including the number and type of passing road vehicles (private cars, heavy lorries, two-wheeled vehicles), the passage of trains and the flights of aircraft, etc. During entire measurement period the course of making the 305 recordings, the operators listed a total of 1900 events (excepting road traffic) including 337 (18%) aircraft flights, 272 (14.5%) passages of trains and a total of 204 (10.9%) sounding of horns, etc. Aircraft flights were taken into account for 95 recordings (an average of 3.5 flights) and the passage of main line trains for 62 recordings (an average of 4.4 passages).

Conclusion of the study:

- As per questionnaire survey, noise was noted in 56.4%, air pollution in 23.8% and other effects in less than 10% of the replies.
- With respect to noise source, Road transport 47%, compared with 32% for undesirable effects originating from adjacent habitations and 12% from all other surroundings. Air transport (4.6%), rail transport (3.2%) and the metro underground railway (0.6%).

2.5 Noise impact measurement in metro railway platforms

2.5.1 Characteristics of train noise in above-ground and underground stations with side and island platforms

The study on characterisation of train noise in overground and underground stations with side and island platforms was conducted by *Shimokura and Soeta (2011).* This study showed that railway stations could be principally categorised by their locations, i.e. overground or underground stations, and by their platform styles, i.e. side or island platforms. However, the effect of the architectural elements on the train noise in stations was not well understood. The aim of the study was to determine the different acoustical characteristics of the train noise for each type of station. The train noise was evaluated by:

(1) The A-weighted equivalent continuous sound pressure level (LA_{eq})
(2) The amplitude of the maximum peak of the **inter aural cross-correlation (IACC)** function
(3) The delay time (t_1) and amplitude (f_1) of the first maximum peak of the auto-correlation function.

The IACC, t_1 and f_1 are correlated to the subjective diffuseness, pitch and pitch strength, respectively. Considering the locations, the LA_{eq} in the underground stations was 6.4 dB higher than that in the overground stations, and the pitch in the underground stations was higher and stronger. Considering the platform styles, the LA_{eq} on the side platforms was 3.3 dB higher than on the island platforms of the above-ground stations. For the underground stations, the LA_{eq} on the island platforms was 3.3dB higher than that on the side platforms when a train entered the station. It was observed that the IACC on the island platforms of the overground stations was higher than that in the other stations.

Demonstration of result from the aforesaid study

Averaged LA_{eq} in the underground stations was 6.4dB higher than that in the overground stations. The t_1 and $f_1$in the underground stations were shorter and larger than those in the overground stations respectively. For the overground stations, the averaged LA_{eq} and IACC on the side platform were 3.3dB(A) higher and smaller than those on island platforms. For the underground stations, the averaged LA_{eq} on island platforms were 3.3 dB higher than those onside platforms when a train approaches into the station. It was also noted that at the entrance and exit of the platform LA_{eq} were very high, when a train comes into and goes from the station, respectively. Technological upgradation in the design of trains and tracks (e.g., wheel absorbers, damping devices, variable-frequency drives and long rails without joints) has reduced train noise. Controlling of train noise sources was the most important agenda of the industrial research and development for this reason there was little consideration of the sound field in stations. The results of the study suggested that the acoustical design of stations can make less noisy effect on the environment. The train noise at the entrance end of the platform indicated the highest value of the LA_{eq}, and the importance was to reduce the noise transmission from the tunnel when the train approached the underground station, for example, they suggested a platform screen with doors. Such a platform screen was often used to separate the track and platform for safety reasons. However, it would also help insulate the train noise from the tunnel and improve the acoustical environment in an underground station.

2.5.2 Change of acoustic characteristics caused by platform screen doors in train stations

In this study conducted by *Soeta & Shimokura (2012),* it was observed that railway companies were encouraged to set up platform screen doors (PSDs) for safety purpose in Japan. The PSDs worked as a barrier of train noises in stations but the effects of those were not well understood. The aim of the study was to clarify the impacts of PSDs on acoustic characteristics of metro stations. In this study there was two types of PSDs were observed in metro stations i.e., mobile full-height (MFH) and mobile half-height (MHH). Train noises were monitored in ground and underground train stations with MFH, MHH and without PSDs. In this work noises were determined by noise level, the maximum peak of the inter-aural cross-correlation function (IACC), and the width of the first decay (WU (0)) of the autocorrelation function. Train noise was reduced by PSDs in both overground and underground stations. It was also observed that, IACC was reduced by the application of PSDs in both ground and underground stations, indicated that PSDs made train noises more diffused. Width of the first decay (WU (0)) was also reduced by the application of PSDs in both overground and underground stations, which suggested that the train noises in station with PSDs had higher spectral centroid, from this it was indicated that the PSDs blocked the lower frequency components of train noise.

From this study it was seen that, train noise in stations was made nuisance in different ways on passengers, reduced the speech intelligibility of public address (PA) systems in stations, and had a risk of causing noise-induced hearing loss (NIHL) for passengers, railway workers and operators. There was not so much acoustical care had been taken on metro stations. In that point of view, the control of train noise in stations was important task for the comfort, convenience and safety of passengers, transit workers and station staff. There were diverse architectural conditions of stations was observed, and their noise fields varied according to station type. The effects of location, an aboveground or underground station, and platform style, side (two platforms at the side and the rail tracks in the centre) or island (one platform at the centre and the rail tracks at the sides) on train noises in stations had also examined at that moment.

Discussion on the result of the study

The results described that the noise level in the case of underground stations was 6.4 dB higher than that in the case of overground stations; pitch and pitch strength were also higher and stronger in the overground stations; and the noise level in underground stations with island platforms, which are the most widely used in Japan for economic reasons, was higher than those with side platforms. This study revealed the fact that acoustic treatment was necessary especially for underground stations with island platforms.

Among approximately 9500 train stations in Japan 4% of those stations had installed PSDs. It was also noted that in the year 2008 there were more than 200 accidents causing injury or death in those stations. From this study it is known that over a two-year period from 2008 to 2010, 61 train stations installed PSDs.

Aim of the above study

The aim of the above study was to explain the effects of PSDs on acoustical characteristics. In this study two types of **Platform Screen Doors (PSDs)** were considered, i.e. **mobile full-height (MFH)** and **mobile half-height (MHH)** as shown in **Fig-2.2**. The PSDs made barrier against the train noises in stations but the train conditions would also affect the acquired acoustic characteristics of train noise. In accordance to the condition of the trains in the station, the train noise was analysed at three time intervals. In this case for evaluating the train noise quantitatively and qualitatively, noise level, for example, the **A-weighted equivalent continuous sound pressure level (LA_{eq})** and parameters extracted from **inter-aural cross-correlation function (IACF)** and **autocorrelation function (ACF)** were used.

(a) Mobile full-height (MFH)

(b) Mobile half-height (MHH)

Fig-2.2: Two types of platform screen doors (PSDs)

(*Source: Soeta and Shimokura (2012)*)

Methodology of the study

Stations covered

The train noise was monitored in twenty-four overground and underground stations with MFH, MHH, or without PSDs on fourteen railway lines **(Table-2.3)**. In this study the dimensions of stations were measured using a laser distance meter (DISTO, Leica), and the architectural data are listed in **(Table-2.3)**. The descriptions of the dimensions are shown in **Fig-2.3**. In each station, three receiver positions were fixed, the first at the entrance end (r_1), the second in the middle (r_2) and the third at the exit end (r_3) of the platform. Train noise was monitored at different times, the maximum noise level (L_{max}), the noise level which was exceeded for 10% of the time of the measurement duration (L_{10}), and the background noise level in the station(L_{bn}). These measurements are shown in **(Table-2.3)**. The types of trains which were running through stations are listed in **(Table- 2.4).**

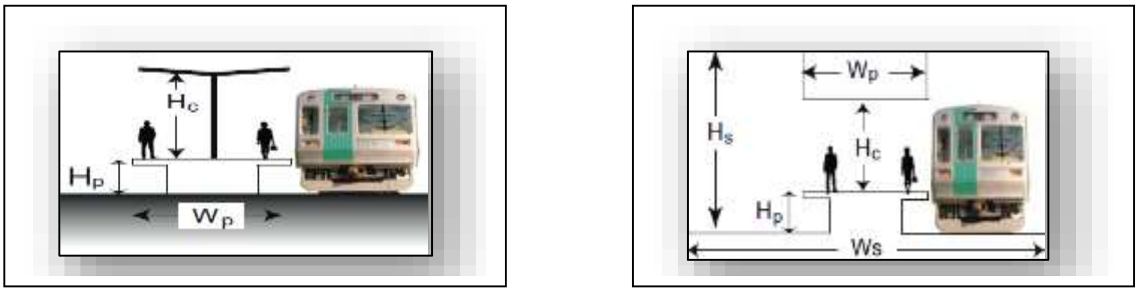


Fig-2.3: Cross-sectional designs of the (a) aboveground and (b) underground *(Source: Soeta and Shimokura (2012))*

Table-2.3: Tabulation of recorded train noise in 24 overground and underground stations with MFH, MHH, or NSD on 14 railway lines

Line	Station	Location	PSD	Dimension of station						L_{max}	L_{10}	L_{bn}
				Ws	Hs	Wp	Hp	Lp	Hc			
A	aF1	Aboveground	MFH			5.2		55.2	2.9	86.8	78.6	63.2
	aF2					7.1		50.6	2.9	83.3	72.1	60.9
B	aF3					5		50.5	2.9	83.4	73.2	64.7
	aF4					6.2		55.2	2.9	89.6	82.0	75.9
C	aH1	Aboveground	MHH	17.3		9.1	1.5	127.1	6.0	89.7	79.5	61.9
	aH2					6.2	1.5	121.8	7.3	89.5	78.3	60.6
	aH3			15.8		7.2	1.5	121.7	5.8	85.6	78.7	55.6
D	aH4					5.1	1.3	128.5	5.1	86.4	77.2	74.5
E	aN1	Aboveground	NSD			7.6	1.3	181.4	4.1	91.1	78.7	68.1
	aN2					5.5	1.2	166.0	3.5	92.2	78.1	59.4
F	aN3			20.5		11.5	1.5	201.3	4.2	93.9	81.3	53.7
	aN4					6.3	1.2	200.0	3.4	81.4	73.3	52.8
G	uF1	Underground	MFH	14.6		7.3		105.7	2.6	91.7	78.6	58.6
	uF2			13.9		6.6		105.8	2.6	96.8	82.5	75.3
H	uF3			17.0		8.2		201.3	3.2	92.1	82.7	54.5
	uF4			13.5		3.0		173.2	2.7	89.8	80.6	55.7
I	uH1	Underground	MHH	14.2	3.8	7.6	1.1	83.6	2.7	83.8	74.2	60.3
	uH2			14.1	4.3	6.5	1.4	143.9	3.0	90.1	79.3	51.5
J	uH3			14.7	3.8	8.0	1.4	204.7	2.9	90.9	82.0	59.0
	uH4			15.8	3.1	8.4	1.2	120.8	2.2	95.4	83.4	52.4
K	uN1	Underground	NSD	14.7	3.9	8.0	1.3	125.5	3.0	94.5	88.1	56.2
L	uN2			14.0	4	7.1	1.3	129.6	3.0	103.5	81.4	58.6
M	uN3			14.7	3.8	8.0	1.4	204.7	2.9	87.5	81.2	47.4
N	uN4			15.7	3.1	9.4	1.0	137.5	2.3	97.6	88.1	65.0

(Source: Soeta and Shimokura (2012))

Table-2.4: Types of train on each line

Line	Train type	Pantograph	Control unit	Brake system
A	2000	Automated guideway transit	Variable-frequency drive	Regenerative brake
B	1000	Automated guideway transit	Reversible type thyristor Leonard control	Regenerative brake
C	1000 2000	Overhead line	Variable-frequency drive	Regenerative brake
D	3000 5080	Overhead line	Variable-frequency drive	Regenerative brake
E	103 201 221 223	Overhead line	Registance control Chopper control Registance control Variable-frequency drive	Dynamic brake Regenerative brake Regenerative brake Brake by wire technology
F	3000 5000 6000 7000 8000	Overhead line	Registance control Chopper control Variable-frequency drive	Electro-pneumatic straight air brake Dynamic brake Regenerative brake
G	50	Overhead line	Variable-frequency drive	Regenerative brake
H	9000	Overhead line	Variable-frequency drive	Regenerative brake
I	3000	Overhead line	Variable-frequency drive	Regenerative brake
J	12	Third rail	Chopper control/variable-frequency drive	Regenerative brake
K	10	Overhead line	Variable-frequency drive	Regenerative brake
L	1000 2000 3000	Overhead line	Chopper control	Regenerative brake
M	3000 9000	Overhead line	Variable-frequency drive	Regenerative brake
N	12-000	Overhead line	Variable-frequency drive	Regenerative brake

(Source: Soeta and Shimokura (2012))

In this study, the effects of PSDs on acoustic characteristics in train stations were determined by noise levels, IACF and ACF parameters. From this study it is observed that when a train approached or left in both overground and underground stations, MHH reduced train noise level. PSDs enhanced the diffuseness or ambiguity of the noise source when a train approached or left. There was the shift of the spectral centroid of noises from low to high noted due to PDSs.

2.6 Noise impact measurement within metro railway: Abroad Scenario

2.6.1 Determination of directivity of railway noise at different speeds

Zhang X. (2010) conducted a study on **determination of directivity of railway noise at different speeds. Directivity** is an important parameter which describes the physical characteristics of the sound generation procedure. In the study the directivity of railway noise was estimated by both direct measurement and theoretical investigation. There were two most important types of noise, i.e. rolling noise and aerodynamic noise, generated when a train is moving on rolling track. A perpendicular dipole pair model was proposed to describe the measurement specified directivity characters of wheel (or rail) radiation. From this model it is understood that why a vibrating railway wheel did not present dipole directivity character and why rail radiation was of different vertical and horizontal directivity characters. It was found that the model of perpendicular dipole pair can properly describe the measurement specified directivity characteristics of wheel/rail vibration noise and pantograph noise and unintentionally, turbulent boundary layer noise and scattered fluid sound also create a perpendicular dipole pair, although the latter prevails in sound power. In this study it was seen that aerodynamic noise around bogies, scattering of the airflow was proposed to be the mechanism of the noise generation; this perceptive led to a different directivity description for the noise component. Directivities of other significant noise types were discussed as well; their directivities were understood, although lacking of relevant directivity data. In conclusion, this study provided applicable directivity functions together with a survey of the directivities of all important railway noise types and components.

2.7 Metro noise measurement both in metro rakes and platforms: Abroad Scenario:

2.7.1 Noise assessment inside the Greater Cairo Underground second-line Metro

Aly M. E. (2005) conducted noise quality assessment inside the Greater Cairo underground second line metro. The study shows that, underground metro rails, which connect different stations of big crowded cities, are the best means of public transportation. In this study it is seen that the electrically operated metro rail was environmentally friendly and did not emit chemical air-pollutants. This was also noted that the number of passengers used the Greater Cairo Underground Metro approximately two million per day, beside about one thousand workers in the different activities related to the metro. Metro users and workers complained regarding the high noise levels produced by metro units travelling in the tunnels, especially at the turns, the entrance of tunnels and at stations while braking.
There are adverse health effects due to that high noise levels for a prolong period: either auditory, such as temporary and permanent hearing loss, or extra-auditory such as effects on the cardiovascular system, blood pressure, heart and respiratory rates, central nervous system. Noise also leads to mental stress problems such as lack of concentration, leading to major accidents. Noise has adverse impacts on psychological, biological, immunological and hormonal systems of the body. Due to the afore-said reasons, it was suggested that the study had been made to start for assessing and diagnosing those problems, and to find the proper methods for early detection and proper management of those health hazards; in addition to the engineering solutions for the noise problem. Noise monitoring had made inside the rakes while travelling and outside the units at the stations platforms to evaluate the noise annoyance and to suggest some kind of solutions to the problem. In this study calculations of different noise indices had

made and compared with international criteria and national standards. The comparison suggested that the noise levels were clearly unacceptable, for indices **L_1, L_{99}, and L_{NP}**, both inside the metro units and outside the units at station platforms along the passage.

Measurements of the above study

The equivalent sound level L_{eq} (in dB(A)), had monitored during the hours starting from 07:00 am to 09:00 pm at the platform of each station inside the tunnel, and inside the metro units between stations, using the **Precision Integrating Sound Level meter B & K 2230 and B & K mediator 2238** for a whole month. Measurements were conducted for the stations from El-Gamaah to El-Mezallat, and were used to determine some noise indices for comparison with the international standards of noise exposure.

Result & Discussion of the aforesaid study

Determination of the percentile noise indices L_1, L_{10}, L_{50}, L_{90}, L_{99}, and the Noise Pollution Index (L_{NP}) were made through making the cumulative curve for each level versus time curve, by which the percentile noise indices, L_1, L_{10}, L_{50}, L_{90} and L_{99} directly obtained from the curve.

- L_1 denotes the maximum noise events, like the fast noise events like train air siren, which takes about 1% of the monitoring period.
- L_{10} is the peak noise index, which indicates the level exceeded for 10% of the monitoring period.
- L_{90} is the noise climate index, which signifies the noise level exceeded for 90% of the monitoring period.
- L_{99} denotes the background noise level, which represents mostly the lowest noise level during the entire monitoring duration.
- $L_{eq}= \int_0^t \left[\frac{\mathrm{P(e)}}{\mathrm{P_{ref}}}\right]^2 \mathrm{d}t$ dB (Hasting & Peacock 1975) where, $P_e$is the effective pressure which is determined for the particular sound wave in units of force per square length, $P_{ref}$is the reference effective pressure.
- The noise pollution index (L_{NP}) can be determined from the expression **($L_{NP} = L_{eq}$+ 2. 56σ)**, where σ = the standard deviation of the readings (Don & Rees 1985).

US Department of Housing and Urban Development adapted the criteria for L_1, $L_{99}$and L_{NP} from noise sources other than aircraft noise had classified in **Table-2.5 (United States Department of Housing and Urban Development (HUD), 1971, 1985)**. **Fig-2.4** suggests the maximum noise events index *(*L_1*)* calculated from the measurements of noise levels, measured in dB(A), inside the metro units between the stations compared with the criteria adopted by the **US Department of Housing and Urban Development (USHUD)**. It is observed from the figure that the maximum noise event index L_1 inside the units was very high and exceeds the limit of the clearly unacceptable range which is greater than 86 dB(A). The calculated value of L_1 ranges from 87.8 to 102.5 dB(A), so it exceeds the limit by about 1.5 to 16.5 dB(A). Due to the tunnel entrance and the sharp turn of 90º, which increases the slip between the wheels and the rails, which in turn increases the noise emission for that reason the value of L_1increased between El-Gamaah and El-Behoos stations.

Table-2.5 USHUD criteria for L_1, L_{99} and L_{NP}

$L_1 < 63{\cdot}5$ dB(A) Clearly acceptable
$63{\cdot}5 < L_1 < 73{\cdot}5$ dB(A) Normally acceptable
$73{\cdot}5 < L_1 < 86{\cdot}0$ dB(A) Normally unacceptable
$L_1 > 86{\cdot}0$ dB(A) Clearly unacceptable
$L_{99} < 35{\cdot}0$ dB(A) Clearly acceptable
$35{\cdot}0 < L_{99} < 53{\cdot}0$ dB(A) Normally acceptable
$53{\cdot}0 < L_{99} < 68{\cdot}0$ dB(A) Normally unacceptable
$L_{99} > 68{\cdot}0$ dB(A) Clearly unacceptable
LNP $< 58{\cdot}0$ dB(A) Clearly acceptable
$68{\cdot}0 <$ LNP $< 73{\cdot}0$ dB(A)Normally acceptable
$73{\cdot}0 <$ LNP $< 88{\cdot}0$ dB(A) Normally unacceptable
LNP $> 88{\cdot}0$ dB(A) Clearly unacceptable

(Source: Aly M. E. (2005))

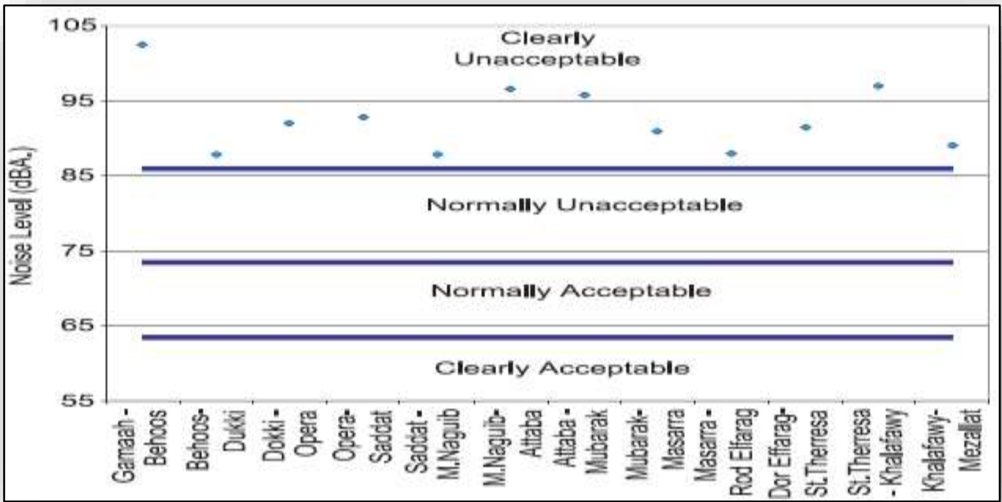


Fig-2.4: Maximum noise level (L_1) inside the metro units compared with the criteria for L_1. (*Source: Aly M. E. (2005))*

Fig-2.5 shows the maximum noise events index (L_1) at the station platforms determined from the measurements of noise levels, expressed in dB(A), and compared with the criteria adopted by **USHUD**. It is observed in the study that the noise sources at the platforms were the aerodynamic and mechanical noises of the train, the train siren, the brakes when applied, the passengers themselves and the attention signal sound systems. The figure represents that the maximum noise events index (L_1) at the 2nd line of the GCUM station platform was between 100.6 dB(A) at the El-Khalafawy station and 107.65 dB(A) at the El-Attaba station. L_1 values at all the stations were in the range of clearly undesirable according to the USHUD criteria. From the study it is observed that the main source of noise at El-Attaba station was the use of the train siren, because this station lied between two turns and for made alert to the passengers waited at the platform could not see the arrival of a train, drivers use that siren. This station was also one of the most crowded stations (about one million passengers/day) because it was situated at the centre of the city.

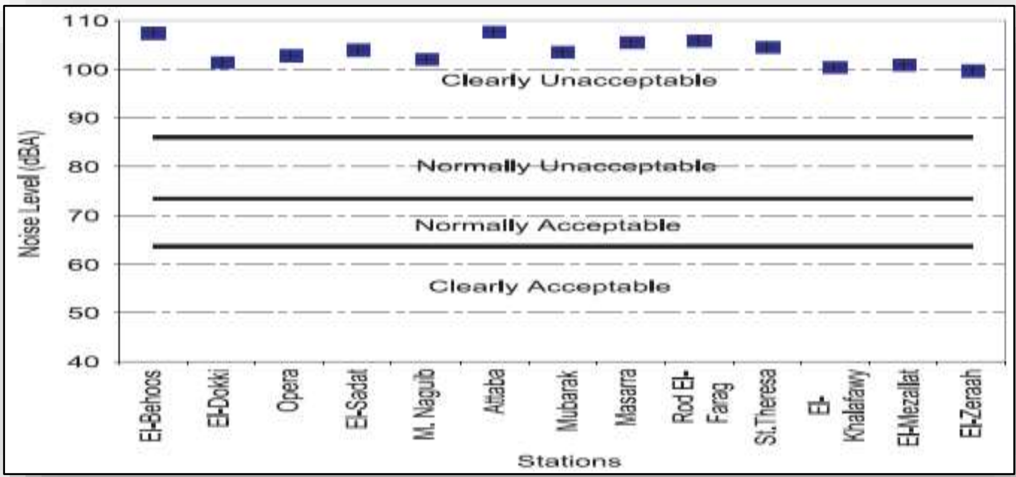


Fig-2.5: Maximum noise level (L_1) outside the metro units compared with the criteria for L_1 *(Source: Aly M. E. (2005))*

Fig-2.6 describes the background noise index **(L_{99})** calculated from the determinations of noise levels measured in dB(A) inside the metro units between the stations, and compared with the criteria adopted by USHUD. From the **Fig-2.6**, it is clear that the background noise index L_{99} inside the units varied from 68 dB(A) between Masarra and Rod El-Farag stations to 77.5dBAbetween Opera and Sadat stations. The comparison reveals the fact that the background noise index L_{99} was in the range of clearly undesirable according to the **USHUD** criteria for all the underground passage of the metro. It is observed from this study that the background noise sources were mostly the interaction between the train and the air around it and between the train and tunnel walls, called aerodynamic noise, and the rail wheel interaction called mechanical noise. Background noise was increased due to the increase of mechanical noise, which also rose due to the increase of unit speed.

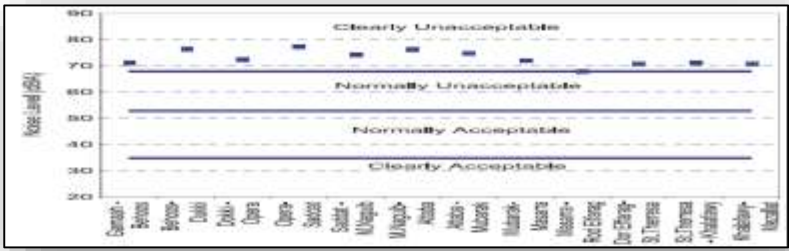


Fig-2.6: Background noise index (L_{99}) inside the metro units compared with the criteria for L_{99}. *(Source: Aly M. E. (2005))*

Fig-2.7 signifies the background noise index (L_{99}) determined from the measurements of noise levels in dB(A) outside the metro units at station platforms compared with the criteria adopted by **USHUD**. It was clearly observed from the figure that the background noise index L_{99} outside the units at the platforms varies from 71.6dB(A) at El-Khalafawy station to 82 dB(A) at El-Behoos station. The comparison suggests that the background noise index L_{99} at all the stations inside the tunnel was varying in the range of clearly unacceptable, according to the USHUD criteria. This study reveals that main sources of background noise were the application of brakes, the sound systems at the platforms and the noise of the passengers' conversation.

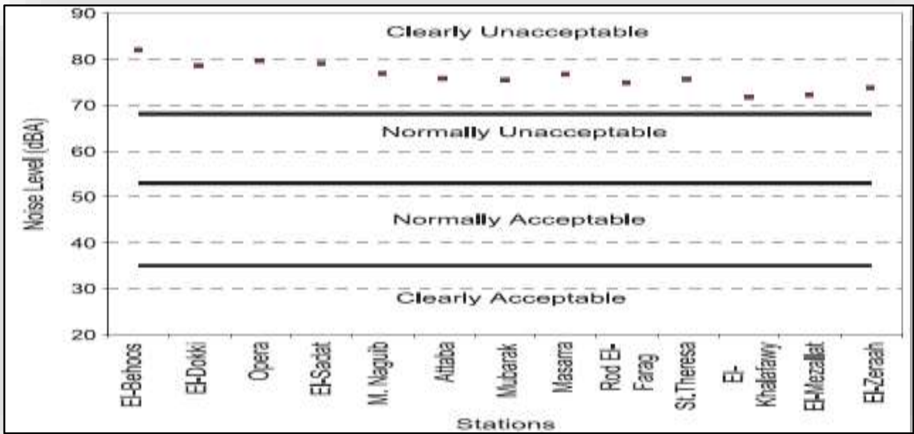


Fig-2.7: Background noise index (L_{99}) outside the metro units compared with the criteria for L_{99} *(Source: Aly M. E. (2005))*

Fig-2.8 shows the **Noise Pollution Index (L_{NP})**, calculated from the measurements of noise levels measured in dB(A), inside the metro rakes between stations, and compared with **USHUD** criteria. The **noise pollution index** took into account the deviation of the readings from the mean L_{NP} varied from

93.5dBAbetween El-Behoos and El-Dokki stations to 126.4dB(A) between El-Gamaah and El-Behoos stations. The comparison used the L_{NP} criteria suggested that the noise pollution level along the entire passage in the tunnel was in the range of clearly undesirable. From this study it is observed that the increase in L_{NP} value between El-Gamaah and El-Behoos stations was due to the entrance of the tunnel, which enhanced the aerodynamic noise, and also due to the sharp turn of 90° between these two stations and the mechanical noise of multiple applications of the brakes to decrease speed at the turn, and to the slipping of the wheels on the rails. This is also seen that the increased in L_{NP} between the other stations was due to the increased in the mechanical noise because of application of brakes to reduce the speed and the aerodynamic noise due to the increase of speed.

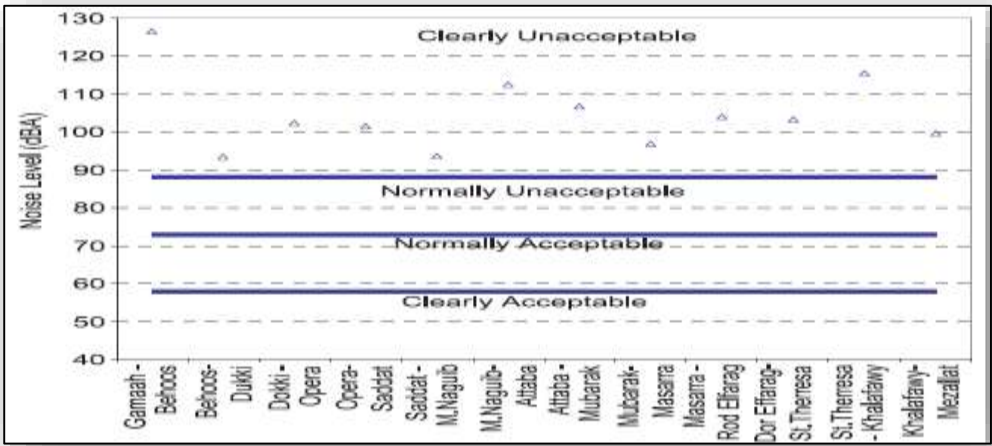


Fig-2.8: Noise pollution index (L_{NP}) inside the metro units compared with the criteria for L_{NP} *(Source: Aly M. E. (2005))*

Fig-2.9 describes the L_{NP} determined from the measurements of noise levels expressed in dB(A) outside the units at the station platforms, and compared with the USHUD criteria. This figure described that the variation of L_{NP} from 104 dBA at the El-Mezallat station platform to 107.3dBA at El-Attaba. Comparison of L_{NP} with the criteria suggested that the L_{NP} values at all stations were in the range of clearly undesirable. Enhancement of L_{NP} occurred due to the use of the train siren and the application of brakes to stop the trains. This is also observed that due to increase in measured sound levels and standard deviation (σ) L_{NP} values was also increased. The increased in σ is due to the great difference between the recorded noise levels for the train siren and brakes compared with the noise of the passenger’s conversation and the attention-signal sound system.

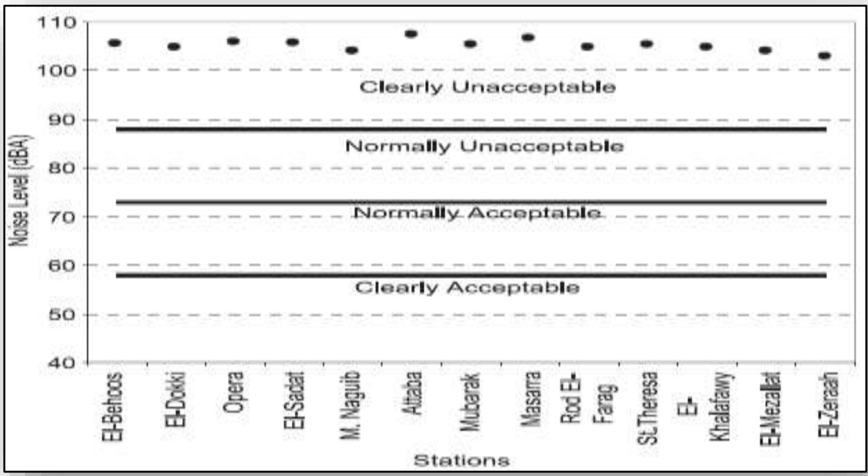


Fig-2.9: Noise pollution index (L_{NP}) outside the metro units compared with the criteria for L_{NP} *(Source: Aly M. E. (2005))*

Conclusion of the study

Afore-said discussion reveals the fact that the noise related problem is very significant especially inside the metro units. From the results of the above study it can be concluded that the enhancement of noise level was due to the lack of air in the ventilation system of the units, which caused the passengers to open the side windows to compensate for the required quantity of air. For this condition external noise entered the metro rakes very easily. The side windows were sound insulating windows, which prevent external noise from entering the units. Noise is reduced approximately 20 to 25 dB(A) for closing of the side windows. Outside the metro rakes mechanical and aerodynamic noise were more prominent than other types of noise, which is increased by reflection of sound from the tunnel walls, due to the cylindrical shape of the tunnel, which reflected the sound from any source to the centre axis of the tunnel along the train's path. Station platforms were exposed to the noise came from application of the air sirens of the trains and the application of the brakes. The enhancement of noise levels at the platforms was also due to the sound reflection phenomenon from the side walls, which were covered with smooth ceramic tiles.

2.8 Case Study for Kolkata Metro

2.8.1 A noise study was conducted in Kolkata Metro Railway by *Mohanan et al. (1989),* the first ever underground tube rail system of India, to inspect the quality of noise levels present could imperil the hearing sensitivity of workers for the metro railway.

Noise monitoring was conducted in two underground metro stations (**Esplanade and Bhowanipore (now Netaji Bhawan)** and one ground metro station (**Tollygunge)**.

2.8.1.1 Specification of Kolkata metro from the study

From this study it is clearly understood the specification of Kolkata Metro which was laid under the roads from Dum Dum in the north to Tollygunge in the south over an entire route length of 16.43 km. It was observed that most of the metro route was in a well-designed concrete tube of box structure, where in a ballast less track had laid for metro movement.

Tunnel specification

From this study it is also known that the concrete tunnel at the platform measures 20 m wide and 9 m high which reduced to 10 m and 6 m respectively along the tunnel route between stations, with the ceiling being 5 m below the ground. The thickness of the box walls was 50 to 60 cm. Underground stations were double-storeyed. The shallow depth mezzanine floor comprised with the houses of the passenger servicing and ticketing facilities, ventilation and air conditioning plants, generators, switch rooms, etc. Ground floor comprised with the island platforms and the tracks.

Ventilation was ensured with giant propeller fans at a rate of 110 m^3/sec through two shafts fitted at each platform.

Operational details of Kolkata Metro Railway

Operational details of Kolkata Metro Railway were shown in the following tabulated form.

Table-2.6: Operational details of Kolkata Metro Railway

Projected length, terminus to terminus	16·43 km
Stations	
overground	2
underground	15
Average interstation distance	1·02 km
Coaches per train	4 or 8
Length of the coach	19·5 m
Width of the coach	2·75 m
Highest speed	80 km/h
Average speed	30 km/h

(Source: Mohanan et al. (1989))

Observed noise sources

In addition, with metro railway noise (auxiliary rail equipment, rail and wheel contact, propulsion system and aerodynamics of the rakes) there was several observed noise sources

i) Ventilation and air-conditioning system
ii) Announcement
iii) Television
iv) Passenger's conversation and activities
v) In the case of ground station (Tollygunje) outside vehicles and human activities

2.8.1.2 Measurement of noise level related to above study

- **Materials used**

i) Noise measurement was conducted using Bruel and Kjaer instruments, pre-calibrated in the laboratory. Steady state noise and vibration levels were monitored in situ as a single parameter.
ii) Frequency analysis of measured noise and vibration level were conducted by an octave filter set attached to the sound level meter.
iii) Fluctuations of noise and vibration levels were recorded using magnetic tape for detailed real-time analysis in the laboratory.

- **Methods**

Measurements of noise and vibrations were conducted at the following positions of above mentioned metro stations using aforesaid instruments at ear level of commuters:

a) Inside the tunnel

b) On the metro platform (Bhowanipore, Esplanade and Tollygunje)
c) Both inside and outside of passenger coach (moving and idling condition)
d) In the driver's cabin
e) At various locations of those metro railway stations (Bhowanipore, Esplanade and Tollygunje)
f) Noise level generated by auxiliary electrical equipment, e.g. compressors, alternators and ventilation fans were also monitored within rakes parked in the metro car shed.
g) Reverberation times and echoes were also monitored on the platform premises.

2.8.1.3 Results and discussion

Observed results of this study may be discussed as follows:

- **Background Noise**
  The A-weighted background (steady-state) noise on both the underground stations at the south end of the platforms were monitored 59 dB(A).
  At the midpoint of the platforms (for all stations), on the entresol level and near the ventilation tunnels of the underground stations, the observed background noise was 69 dB(A) and on the ground station it was 67dB(A). Ventilation system was mainly responsible for that noise.
  It was also detected that, TV announcements and loud conversations were responsible to increase the background noise level at the stations by 5-10 dB(A), depending upon the operational level and the closeness of the noise sources. Rumbling of the tunnel ventilation system and the distinctly audible rattling of the ceiling panels were also responsible to raise the ambient level by about 10 dB(A).

- **Result of noise measurement inside the tunnel**

  Observed ambient noise level near mid-section exhausts inside the tunnel, was 86 dB(A). The movement of the rakes increased this ambient noise level to 102 dB(A).

- **Result of noise measurement at platforms and within rakes**

  The observed noise level for a train idling at the platform was 81 dB(A) in the middle of the platform, 80dB(A) within the rake,77 dB(A) in the driver's cabin and 82 dB(A) near the carriage. As paralleled to these, the noise levels for a moving train were observed 102 dB(A) on the platform, within rakes and driver's cabin it was 92 dB(A) with doors and windows closed, and 108 dB(A) under the carriage.

- **Result of noise measurement for auxiliary machines and electrical equipment**

To investigate the relative contributions of the various auxiliary electrical machines (such as compressors, alternators, fans, etc.) fitted under the carriage and inside the coach, to the total noise, noise monitoring was conducted for these auxiliary machines separately at ear level, at a distance of 1 m from them and inside the coach at the ear level of the seated passengers, with the train parked in the car shed. The measured A-weighted background noise level during these observation was 56 dB(A).

Compressor noise level was 86 dB(A) in its immediate vicinity,72 dB(A) inside the coach with windows and doors closed and 74 dB(A) inside the coach with windows and doors open. Six operating alternators and fans were responsible to contribute a noise level of 73 dB(A) outside the carriage and 80 dB(A) inside the coach with doors and windows closed.

The above measurements had concluded that compressor noise was mainly responsible for the measured noise level on the platform during the period the train was idling on the station, and that fans contributed noticeably to noise inside the coach.

Observed noise shielding property of the coach's body

It was also observed that the body of the coach acts as a shield for the compressor noise, providing noise insulation of 14 dB(A) with doors and windows closed and 12 dB(A) with windows and doors open, i.e. windows and doors offered additional insulation of only 2 dB(A) to the compressor noise inside the coach.

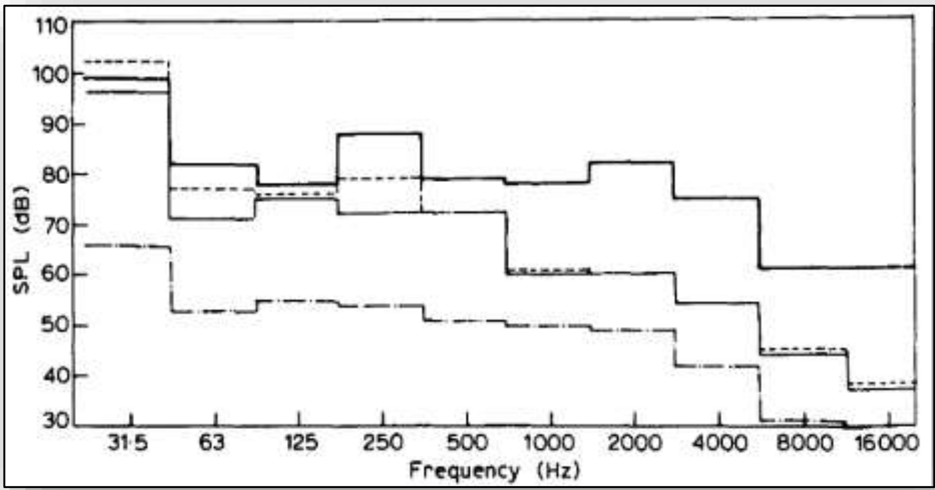


Fig-2.10: Spectral distribution of the compressor noise level at various locations, both inside and outside the coach (Outside the coach 86 dB(A); inside the coach, window open 74 dB(A); inside the coach, window closed 72 dB(A); inside the coach (ambient) 56 dB(A)) *(Source: Mohanan et al.(1989))*

Spectrum profiles of compressor noise observed both inside and outside the coach under various conditions (Fig-2.10) further indicate that compressor noise was more or less uniform in the frequency range 50 Hz-3 kHz and that the coach body offered resistance or shielding of noise (up to 20 dB(A)) in the frequency range above 1000 Hz and low suppression below 1000 Hz.

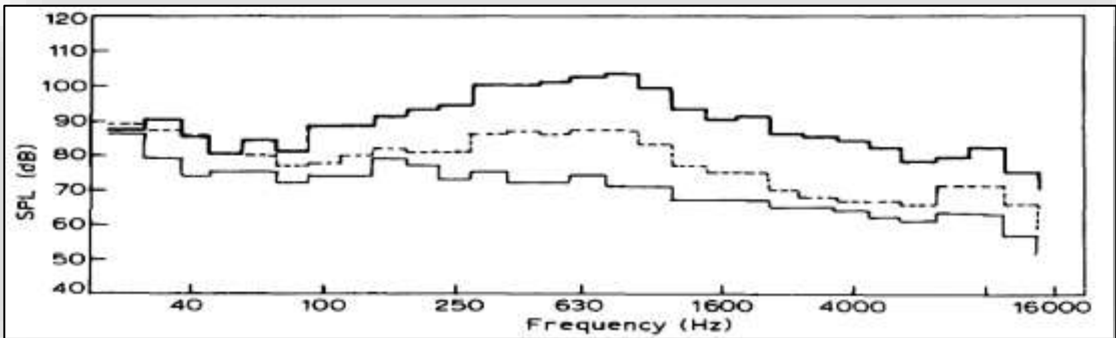


Fig-2.11: One-third octave band analysis of noise inside the passenger cabin and under the carriage for the moving and the idle metro train (Moving train (under carriage) 108 dB(A); moving train (passenger cabin) 92 dB(A); stationary train (passenger cabin) 80 dB(A)) *(Source: Mohanan et al. (1989))*

A spectral analysis of the monitored noise under the carriage and inside the coach of the moving train (Fig-2.11) further indicates that the noise level of the moving train was higher in the middle frequency range. This noise was generated due to rail-wheel contact which was communicated to the inside of the coach through the ventilation system.

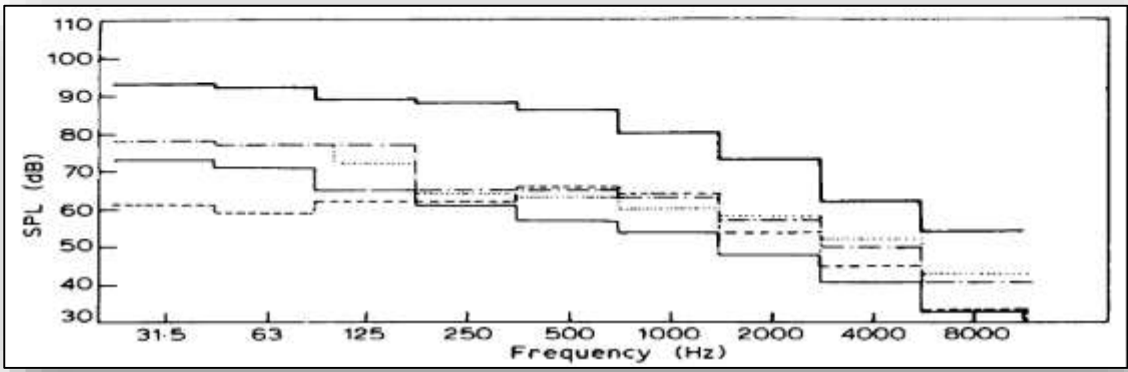


Fig-2.12: Spectral distribution of the background noise level at various locations in the underground stations (At mid section exhaust 86 dB(A); at platform level 68dB(A); at mezannine level 67 dB(A); at platform level (quiet) 59 dB(A) (underground station); platform level 67 dB(A) (ground station) *(Source: Mohanan et al. (1989))*

An analysis of the frequency composition of the background noise at the various locations of the underground stations (Fig.-2.12) was conducted. It is observed that the nature of the spectra in all cases is more or less the similar, during peak periods effects of human activities, announcements, etc., were superimposed on this steady background noise level. The ventilation system was considered to be responsible for the background noise since the observations under quieter conditions were taken when rakes were not operating. The spectral composition of the background noise level at the overground station of Tollyganj is, however, different, sources of that noise were ceiling fans, vehicular traffic, announcements and passenger activities, etc.

Theoretical estimation of noise level

It was observed from this stduy, that auxiliary electrical and ventilation systems were responsible for the measured noise for the stationary train, in the case of moving rakes wheel-rail contact, propulsion systems, auxiliary electrical systems, ventilation systems and aerodynamics all together were verily responsible for the observed noise and vibration levels.

This study used the following formulas to estimate the noise levels expected due to aforesaid factors on the basis of normal running conditions of the metro.

$$L_{Awr} = 30\log(V/V_0) + 60 \text{ dB}$$

(Source: Mohanan et al. (1989))

Where, L_{Awr} is normalized A-weighted SPL at a distance of 25 m, V is the rail car speed in km/hr and V_0 is the reference speed 24km/hr.
From this relation, calculated normalised A-weighted sound pressure level (maximum) was 76 dB(A), for a speed of 80 km/h.
The prediction of wheel-contact noise by L_{Awr} was suitable, provided an allowance of an increase in noise level of 10 dB(A) due to ballast less absorptive track and subway tunnel reverberation was allowed in comparison to the track exposed in the open air.

Traction motor noise (L_{Atm}) and gear noise (L_{Ag}) was estimated using following relationship

$$L_{Atm} = 60 \log V + C_1$$

(Source: Mohanan et al. (1989))

$$L_{Ag} = 10 \log V + C_2$$

(Source: Mohanan et al. (1989))

where C_1 and C_2 are constants- C_1= -4.6 at 32km/hr and C_2= 66.7 at 56 km/hr

Using these values, calculated traction motor noise and gear noise, at a distance of 4.2m from the central line, were 73.5dB(A) and 82.1dB(A) respectively.

In this study, aerodynamic noise was assumed negligible compared to other noises for the usual speeds of 80 km/h (maximum) for the Kolkata metro rail.

In consideration with the above-estimated noise levels and the fact that ballastless absorptive track and subway tunnel reverberation increased the under-carriage noise level by a maximum of 10 dB(A) in comparison to a track exposed in the air, the monitored high interior noise levels of the Kolkata metro were due to factors other than those given above.

Studies of occupational hazard and passenger discomfort

To investigate the occupational hazard to the passengers, train drivers and other staff exposed to noise, determination of short-term equivalent noise level (Leq) and percentile exceeded noise levels (L_N levels) was conducted within the passenger coach, in the driver's cabin and under the carriage, travelled for a duration of 10 min between Esplanade and Tollygunje. The study results are presented in Table-2.7.

Table-2.7: Statistical distribution of background noise levels within moving metro rakes

Location	L_N *Levels (dB(A))*			
	L_{10}	L_{50}	L_{90}	L_{eq}
Under the carriage	109·0	97·5	82·5	103·5
Inside the passenger coach	92·0	87·5	80·5	87·0
Driver's cabin	89·0	83·5	77·0	85·5

(Source : Mohanan et al. (1989))

From the observations in Table-2.7 , it was noticed that the peak noise level (L_{10}) measured under the carriage was 109 dB(A), while inside the passenger coach peak noise(L_{10}) was 92 dB(A) and 89 dB(A) in the driver's cabin. The background noise level (L_{90}) was likewise 82.5 dB(A), 80.5 dB(A) and 77.0 dB(A) under the carriage, inside the passenger coach and in the driver's cabin respectively.

The analysis further shows that the noise level mostly ranges from 80 to 90 dB(A) inside the coach and from 75 to 85 dB(A) in the driver's cabin. A similar computation of equivalent noise level (L_{eq}) shows that it was under the carriage 103.5 dB(A), inside the passenger coach it was 87 dB(A) and at driver's cabin it was 85.5 dB(A).

Table-2.8: Noise exposures associated with various types of transport

Type of vehicle	*Exposure level (dB(A))*
Motor cars	65–85
Buses, trains	75–95
Trucks	80–90
Passenger aircraft	80–95

(Source: Mohanan et al. (1989))

In comparison with the noise levels of main line freight and passenger trains operating on ballast and tie track under similar speed conditions as metro rakes, the noise level of the metro inside the tunnel was 90 dB(A) higher than the noise levels of main line freight and passenger trains. This behaviour was obviously expected since reverberation in the tunnel adds to the noise level.

Anyway, the noise exposure of the commuters inside the metro coache was also likewise similar to that associated with various types of transport, as given in Table-2.8. Above mentioned noise exposure can responsible for occupational hazards, inconvenience and discomfort to passengers.

Present study was focused on the **World Health Organization's (WHO)** general recommendations on noise exposure limits (Table-2.8) describing the possible effects on the physical condition of persons in the trains overshooting those limits.

Table-2.9 Summary of WHO's recommended exposure limits and the effects of overshooting these limits

Industrial/occupational	75	Predictable risk of hearing impairment at higher levels
Community/urban		
daytime	55	Annoyance increases at higher levels
night-time	45	Difficulties in falling asleep at higher levels
Indoor/domestic		
daytime	45	Speech communication deteriorates at higher levels
night-time	35	Increased awakening at higher levels

(Source: Mohanan et al. (1989)

Table-2.10: WHO Recommended noise criteria for steady background noise

Type of space	Average noise level (dB(A))
For just-acceptable speech and telephone communication (metro platforms)	65
Where speech or telephone communication is not required, but no risk to hearing (inside moving metro trains and driver's cabin)	80

(Source: Mohanan et al. (1989))

Daily exposure of 75 dB(A) equivalent noise level for 8 hour above 40 years aged human beings may led to the permanent hearing disorders. Recommendations for the maximum allowed noise dose for persons working in noisy environments (occupational noise hearing loss) was worked out taking into account time varying noise levels and durations by the International Organization for Standards. The prescribed noise dose was 90 dB(A) for a normal working day of 8 h and 40 h/week to which an employee can be subjected to before he expose to a significant risk of permanent hearing loss. Continuous exposure to 90 dB(A) L_{eq} on human being for 8 h/day over more than 20 years led to permanent deafness.

By considering the above hearing damage risk on noise exposure prevailed the fact that that the crew members were carried a risk of hearing damage due to exposure to metro noise if they work for more than the prescribed hours during the week and also if they work on the same job for a long period of their service. Noise exposure on passengers was not able to enforce them into such a high risk due to their short journey duration. They were disturbed or inconvenienced in terms of aural communication (speech, listening to public address systems and television, etc.).

As per analysis with respect to Speech Interference Levels (SIL) and other prescibed noise criteria (Table-2.10) for intelligibility under prevailing noise levels on the platforms and inside the carriage, there were a general loss of clarity and it was difficult to converse. The commuters were felt annoyance since noise level exposure was generally higher than the WHO's recommended limits.

2.8.1.4 Conclusion of the above study

Observed noise levels were higher than the prescribed values for comfortable travel and conversation. Due to the higher background noise levels, intelligibility of announcements was also poor,although in the underground station the reverberation time of 0.8 sec was measured in the frequency range of 500-2000 Hz. At the overground stations the authors had measured a reverberation time of 4-5 sec in the same frequency range, which could be responsible for the poor intelligibility there. Analysis of the measured noise had shown that rattling of doors and windows, whistling noise from crevices and grills, air inhaling systems for the coach, higher sweep of the fans, transmission of noise from the auxiliary electrical equipments and the impact pressure of wheel and rail system are responsible for the higher noise levels observed both inside as well as outside the rakes. On the underground stations, noise was mainly due to the ventilation system, train auxiliary equipment and the movement of other trains. On the overground station, outside vehicular traffic and ceiling fans were additionally responsible for the measured noise.

Present study suggested that part of the high noise level studied in the Kolkata metro could be reduced through preventive cares such as proper acoustical insulation and isolation of the coach, better design of the circulation and ventilation systems and the mounting of auxiliary equipments. Further this was suggested that, rattling and whistling noise and vibrations can be effectively controlled through the choice of secure and firm anchoring and the use of rubber gaskets. Use of slow speed fans could also help to reduce air circulation noise to some extent.

The aerodynamic noise was also not bothersome since the train was moved at a low speed with a maximum of only 80 km/h.

2.8.2 Bhattacharya et al.(1996) carried out a noise assesment in Kolkata Metro Railway, India's first ever underground tube rail system, to investigate the quality of metro noise and its exposure to the workers for the metro rakes.

Materials used

In this study a sound level meter, an octave band analyzer, and a sound level calibrator were used for measuring the sound pressure levels in platforms of three stations: Esplanade, Kalighat and Tollygunge.

Observations and comments

The results of this study observed that the averaged A-weighted SPLs in these stations were in the range of 84-87 dB(A). Within the rakes of the moving train the L_{eq} values ranged 92-99 dB(A) and L_{NP} 105-117 dB(A), all exceeding the safe limit of day time noise exposure of 55 dB(A) and 85 dB(A) of American Conference

of Governmental Industrial Hygienists(ACGIH). The measured SPLs at 4,000 Hz in the rakes were also exceeded the safe exposure limit of 79 dB(A).
The findings thus posed a potential threat to the workers.

Virgin area of research

In India, there is very few noise quality survey works conducted for monitoring railway noise within station platforms, railway rakes and in the railway tracks. However, for metro railway the number of such study is negligibly small. The review of available literatures reveals the fact that noise quality monitoring was primarily conducted on metro railway platforms and in metro railway rakes, but there is no such work on monitoring of noise quality in the different types of buildings (residential and commercial) of the **Kolkata** city lying at the immediate vicinity of overground portion of metro railway. Hence, besides noise quality monitoring in metro railway platforms and metro railway rakes, present study was focused on the monitoring of noise quality in different types of buildings of Kolkata city adjacent to the overground metro stations and as well as on the overground station.

Chapter-3

Objective & Scope of the Study

The present study has a definite objective, which is assumed to be fulfilled considering the scopes delineated below:

Objective of Study

The objective of the present study can be summarized as **to assess the quality of noise prevailing in underground and overground metro railway stations of Kolkata city, within the rakes and within the buildings (both institutional and residential) adjacent to overground metro railway stations**.

Scope of the Study

To achieve the work objective of present study following steps have performed:

- Assessment of noise quality prevailing at underground and overground metro railway stations and drawing comparison between them and with respect to the prescribed CPCB standards.
- Assessment of noise quality prevailing within the metro railway rakes during movement.
- Assessment of variation in noise quality between peak and non-peak hours at day and night prevailing at the underground and overground metro railway stations and within the metro railway rakes during movement.
- Assessment of noise quality prevailing at the places (institutional and residential) adjacent to the overground metro railway tracks
- Statistical interpretation of the results obtained during entire course of the noise quality monitoring study.

Chapter- 4

Materials and Methods

4.1 Materials

In the present study the followings instruments were used for measurement of noise quality:

(i) Sound level meter (CESVA(SC160))
(ii) Tripod stand and
(iii) A measurement tape

4.1.1 Working Principle:

Sound level meter CESVA SC160 has a pointy stick at the top, which is the microphone that samples and measures the sound. The stick keeps the microphone away from the body of the instrument, cutting out reflections, and giving a more accurate measurement. Inside the square box at the bottom of the meter, electronic circuits measure the sound detected by the microphone and amplify and filter it in various ways before showing a read out on a digital LCD display.

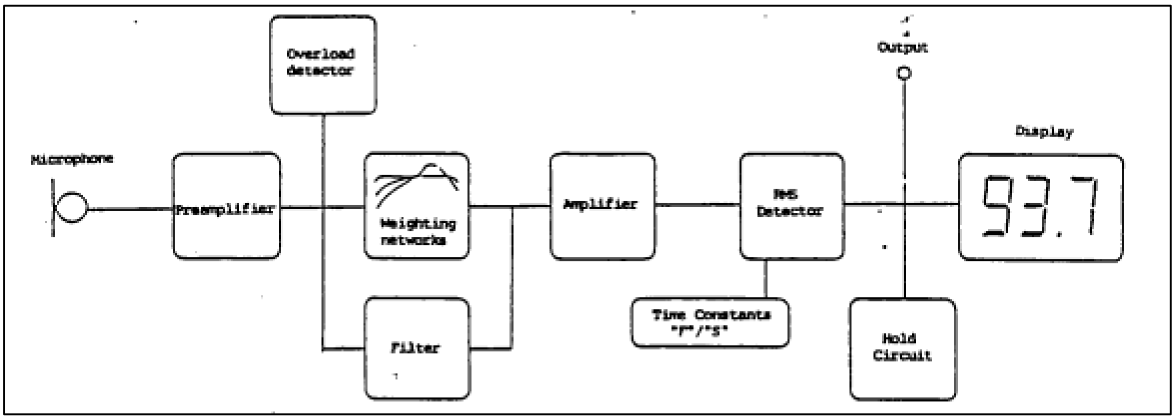


Fig-4.1: Schematic diagram of working principle of noise level meter

Fig-4.2 Noise level meter CESVA (SC-160)

4.2 Work Methodology

The present study was conducted at the following points to assess the noise quality related to Kolkata Metro Railway System-

i) **At two overground stations (Dumdum & Netaji Metro Railway Stations)**
ii) **At two underground stations (Belgachia & Shyambazar Metro Railway Stations)**
iii) **Within metro rakes (both AC and Non-AC)**
iv) **At a school building (Swami Pranabananda Vidyapith) adjacent to Netaji Metro Railway Station**
v) **At a residential building adjacent to Dumdum Metro Railway Station**

The background noise for all these monitoring stations was monitored both at day time **(4:00 AM to 6:00 AM)** and night time **(12:00 AM to 2:00 AM)** when all the major noise producing sources were absent.

In this study, noise quality monitoring was conducted at platforms of afore-said metro railway stations and all other noise monitoring stations at **day-time peak hour (8:00 AM to 10:00 AM)** and **day-time non-peak hour (1:00 PM to 3:00 PM)** and **at night-time peak hour (5:00 PM to 7:00 PM)** and **night-time non-peak hour (8:00 PM to 10:00 PM)** using **noise level meter (CESVA, SC 160).**

Under the purview of the present study, noise quality assessment was conducted to investigate average noise exposure of the commuters in the Kolkata Metro Railway System at each monitoring station. Another noise quality study was made for assessing instantaneous noise level at each metro station for different types of rakes (AC and Non-AC) at peak and non-peak hours of day and night by maintaining 1.0 m distance from noise source at passenger’s ear level.

In this study primarily **A-weighted equivalent noise level (L_{eq})**, and various types of **percentile exceeded noise levels (L_N)** were measured by using noise level meter. From, these percentile exceeded noise level data **noise climate (NC)** and **traffic noise index (TNI)** were determined.

Descriptive statistical analysis of various noise data was performed by SPSS software.

Fig-4.3: Noise study at day non-peak hour for AC rakes

Fig-4.4: Noise study at night peak hour for AC rakes

Fig-4.5: Noise study for Non-AC rakes

Fig-4.6: Noise study within empty rakes

Fig-4.7 Noise study for moving AC rakes at school building

Chapter-5

Results & Discussion

5.1 General

The present study was performed to investigate the noise quality of India's first **MRTS (Mass Rapid Transit System)**. Kolkata Metro Railway System. In this study, noise quality assessment was conducted at various monitoring stations at different operational **(Commercial)** hours **(Peak hour & Non-peak hour)** and **non-commercial hours** of **day and night**, which are considerably exposed to Metro Railway noise. The noise quality monitoring stations considered under the purview of the present study are as follows:

i) **Platforms of two underground Metro Railway Stations** (**Belgachia & Shyambazar**)
ii) **Platforms** of **two overground Metro Railway Stations** (**Dumdum & Netaji**)
iii) **Metro Railway rakes** (both **AC & Non-AC rake**)
iv) **Car-shed** (**Kavi Subhash carshed**)
v) A **School building** (**Swami Pranabananda Vidyapith**) near **Netaji Metro Railway Station**
vi) A **residential building** (Near **Dumdum Metro Railway Station**)

5.2 Results & Comments on results

Results obtained in the present study may be represented and discussed in the following way:

5.2.1 Background Noise Data

In this study background noise was monitored at different non-commercial hours (day & night) for afore-said noise monitoring stations which are considerably exposed to the Kolkata Metro Railway noise.

The day time background noise level was monitored from **5:00 A.M.** to **7:00 A.M.** at different noise monitoring stations with a view to draw a comparison between the noise level persisting at those monitoring stations in presence or absence of major noise producing sources (in this case Metro Railway).

(Fig-5.1 & 5.2) reveal the fact that A-weighted background noise level was maximum for over-ground stations (Dumdum & Netaji), minimum for underground stations (Belgachia & Shyambazar) and in between for the school and the residential house near Dumdum Metro Railway Station.

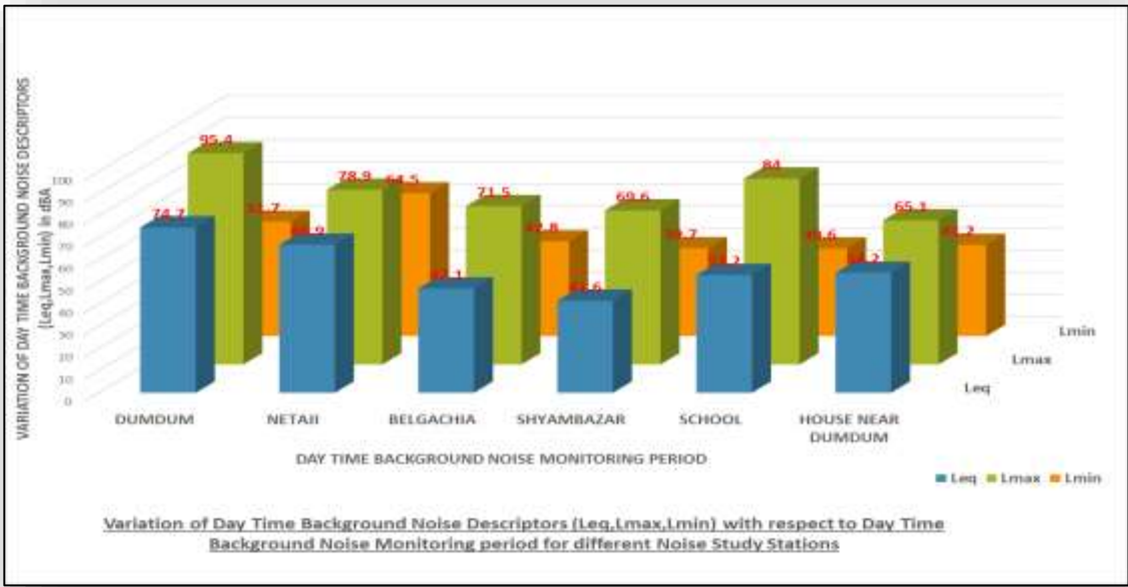


Fig-5.1: Variation of day time background noise descriptors with respect to day time background noise monitoring period for different noise study station

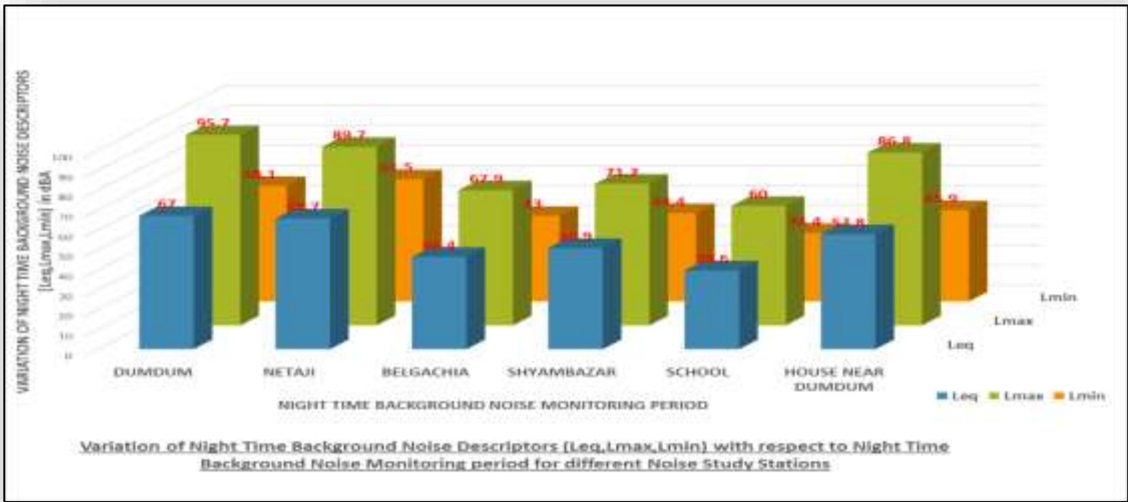


Fig-5.2: Variation of day time background noise descriptors with respect to night time background noise monitoring period for different noise study station

Present study observed that, apart from the time related variation of noise sources and its frequency, sources of these day and night time background noise were, movement of metro worker's by trolley from one station to another through the metro railway track (after disconnection of electric main), operation of electrical machinery, noise from electrical equipment room, ventilation system etc. for underground stations (Belgachia and Shyambazar). At Shyambazar Metro Railway station night time background noise also came from water movement through outlet, bird's movement etc.

For overground station (Dumdum and Netaji) specially for Dumdum Metro Railway station, movement of nearby EMU act as very high background noise sources at day and at night movement of goods train was responsible for this high background noise at night. In case of Netaji Metro Station, outside road vehicle was responsible for day and night time background noise level. Besides these rail and road traffic noise sources there were some other types of noise sources playing important role, e.g.- movement of metro worker's by trolley from one station to another through the metro railway track (after disconnection of electric main), operation of electrical machinery, noise from electrical equipment room etc.

Some extent of this background noise was also contributed by worker's conversation and activities for both types of stations.

5.2.1.1 Background noise (Day & Night) of Dumdum Metro Railway Station

- In the case of **Dumdum Metro Railway station**, maximum day time A-weighted background equivalent sound level (Fig-5.1) was observed as **74.7 dB(A).**
- At night time, background noise of **Dumdum Metro Railway Station** was **67.0 dB(A)** of night time background equivalent sound level (Fig-5.2).

Table-5.1: Descriptive statistical data for background noise (Day & Night time) of Dumdum Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	70.85	74.70	67.00	5.44	7.68
L_{max}	95.55	95.70	95.40	0.21	0.22
L_{min}	54.90	58.10	51.70	4.53	8.24
L_1	77.25	79.70	74.80	3.46	4.49
L_{10}	72.45	76.60	68.30	5.87	8.10
L_{50}	69.30	73.50	65.10	5.94	8.57
L_{90}	61.10	64.00	58.20	4.10	6.71
L_{99}	58.40	63.20	53.60	6.79	11.62
NC	11.35	18.40	4.30	9.97	87.84
TNI	76.50	101.80	51.20	35.78	46.77

From Table-5.1 it may be concluded that the minimum value of L_{eq} is 67 dB(A) and the maximum value of L_{eq} is 74.70 dB(A). L_{eq} has its mean value of 70.85 ± 5.44 dB(A). These values of L_{eq} exceed the respective CPCB standards i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.
TNI value was calculated to evaluate the extent of annoyance of metro railway traffic. TNI has its mean value of 76.50 ± 35.78 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is really annoying the commuters.
In this case the coefficient of variation of L_{eq} was calculated 7.68%.

5.2.1.2 Background noise (Day & Night) of Netaji Metro Railway Station

- For Netaji Metro Railway Station maximum day time background L_{eq} was 66.9 dB(A) (Fig- 5.1).
- In the case of night time background noise (Fig-5.2) of Netaji Metro station L_{eq} was 65.7 dB(A).

Table-5.2: Descriptive statistical data for background noise (Day & Night time) of Netaji Metro Station

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	66.30	66.90	65.70	0.85	1.28
L_{max}	84.30	89.70	78.90	7.64	9.06
L_{min}	63.00	64.50	61.50	2.12	3.37
L_1	71.90	72.70	71.10	1.13	1.57
L_{10}	68.35	68.40	68.30	0.07	0.10
L_{50}	64.55	66.10	63.00	2.19	3.40
L_{90}	63.90	65.40	62.40	2.12	3.32
L_{99}	63.55	65.00	62.10	2.05	3.23
NC	4.45	6.00	2.90	2.19	49.26
TNI	46.70	56.40	37.00	13.72	29.37

From, Table-5.2 reveals that the maximum and minimum value of L_{eq} were 66.90 dB(A) and 65.70 dB(A) respectively. Mean value of L_{eq} was 66.30 ± 0.85 dB(A). These values of L_{eq} exceed the respective CPCB standards i.e., 65 dB(A) for day time and 55 dB(A) for night time for commercial area.
TNI has its mean value of 46.70 ± 13.72 dB(A) which is lesser than the 74.0 dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is less annoying to the commuters.

In this case coefficient of variation of L_{eq} was calculated 1.28%.

5.2.1.3 Background Noise (Day & Night) of Belgachia Metro Railway Station

- From Fig-5.1, it is seen that in the case of underground Belgachia Metro Station maximum day time background L_{eq} was 47.1 dB(A) only.

- In the Fig-5.2, it is clearly observed that night time background L_{eq} was 46.4 dB(A).

Table-5.3: Descriptive statistical data for background noise (Day & Night time) of Belgachia Metro Station

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	46.75	47.10	46.40	0.49	1.06
L_{max}	69.70	71.50	67.90	2.55	3.65
L_{min}	42.90	43.00	42.80	0.14	0.33
L_1	50.50	50.80	50.20	0.42	0.84
L_{10}	47.50	47.90	47.10	0.57	1.19
L_{50}	45.95	46.00	45.90	0.07	0.15
L_{90}	44.90	45.10	44.70	0.28	0.63
L_{99}	44.05	44.20	43.90	0.21	0.48
NC	2.60	3.20	2.00	0.85	32.64
TNI	25.30	27.50	23.10	3.11	12.30

Above table reveals the fact that the maximum and minimum value of L_{eq} were 47.10 dB(A) and 46.40 dB(A) respectively. Mean value of L_{eq} was 46.75±0.49 dB(A). These values of L_{eq} did not exceed the respective CPCB standards i.e., 65 dB(A) for day time and 55 dB(A) for night time for commercial area.
TNI has its mean value of 25.30 ±3.11 dB(A) which is lesser than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is less annoying to the commuters.
In this case coefficient of variation of L_{eq} was calculated 1.06%.

5.2.1.4 Background Noise (Day & Night) of Shyambazar Metro Railway Station

- In the case of, day time background noise monitoring at Shyambazar metro station, L_{eq} was measured as 41.6 dB(A) (Fig-5.1).
- At night time, background noise of this Shyambazar Metro Station platform was observed 50.9 dB(A) (Fig-5.2).

Table-5.4: Descriptive statistical data for Background Noise (Day & Night time) of Shyambazar Metro Station

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	46.25	50.90	41.60	6.58	14.22
L_{max}	70.40	71.20	69.60	1.13	1.61
L_{min}	42.05	44.40	39.70	3.32	7.90
L_1	53.30	62.60	44.00	13.15	24.68
L_{10}	47.10	52.00	42.20	6.93	14.71
L_{50}	43.80	46.10	41.50	3.25	7.43
L_{90}	43.00	45.20	40.80	3.11	7.24
L_{99}	42.55	44.80	40.30	3.18	7.48
NC	4.10	6.80	1.40	3.82	93.13
TNI	29.40	42.40	16.40	18.38	62.53

From above table it may be concluded that maximum and minimum value of L_{eq} were 50.90 dB(A) and 41.60 dB(A). Mean value of Leq was 46.25 ± 6.58 dB(A).
These values of L_{eq} did not exceed the respective CPCB standards i.e., 65 dB(A) for day time and 55 dB(A) for night time for commercial area.
TNI has its mean value of 29.40 ±18.38 dB(A) which is lesser than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is less annoying to the commuters.
In this case coefficient of variation of L_{eq} was calculated 14.22%.

5.2.1.5 Background Noise (Day & Night) of a school building (Swami Pranabananda Vidyapith) near **Netaji Metro Railway Station**

- From figure (Fig-5.1) it is observed that A-weighted day time background noise at first floor level of that school building was 53.2 dB(A). Sources of this background noise were outside vehicular noise, bird's noise and huge amount of noise generated from religious activities pursued at the nearby temple.

- In the context of night time background noise (Fig-5.2) it was seen at that A-weighted L_{eq} was 39.6 dB(A) at first floor level of school building. Night time background noise was generated at that time due to birds' movement and to some extent from outdoor vehicular activities.

Table-5.5: Descriptive statistical data of School's Background Noise

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	46.40	53.20	39.60	9.62	20.73
L_{max}	62.55	65.10	60.00	3.61	5.77
L_{min}	37.80	41.20	34.40	4.81	12.72
L_1	53.05	60.30	45.80	10.25	19.33
L_{10}	48.20	56.40	40.00	11.60	24.06
L_{50}	45.15	51.40	38.90	8.84	19.58
L_{90}	42.45	46.60	38.30	5.87	13.83
L_{99}	40.40	43.20	37.60	3.96	9.80
NC	5.75	9.80	1.70	5.73	99.61
TNI	35.45	55.80	15.10	28.78	81.18

From above table it may be concluded that maximum and minimum value of L_{eq} were 53.20 dB(A) and 39.60 dB(A). Mean value of L_{eq} was 46.40 ± 9.62 dB(A). These values of L_{eq} did not exceed the respective CPCB standards i.e., 65 dB(A) for day time and 55 dB(A) for night time for commercial area.
TNI has its mean value of 35.45 ± 28.78 dB(A) which is lesser than the 74 dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is less annoying to the commuters.
In this case coefficient of variation of L_{eq} was calculated 20.73%.

5.2.1.6 Background Noise (Day & Night) of a residential building near **Dumdum Metro Railway Station**

- The day time A-weighted background noise level at the residential building near Dumdum Metro Railway Station was observed (Fig-5.1) as 54.20 dB(A) at 2^{nd} floor level of that building. Noise producing sources were nearby EMU, conversation of residents, outdoor vehicular activities, bird's noise, electrical equipment's noise etc.

- At night time, background noise was 57.8 dB(A) (Fig-5.2) at same floor level of that residence. Major part of this noise was generated from movement of locomotives and goods train through the railway line near that residential building. Other sources of that background noise were bird's noise, electrical machinery noise etc.

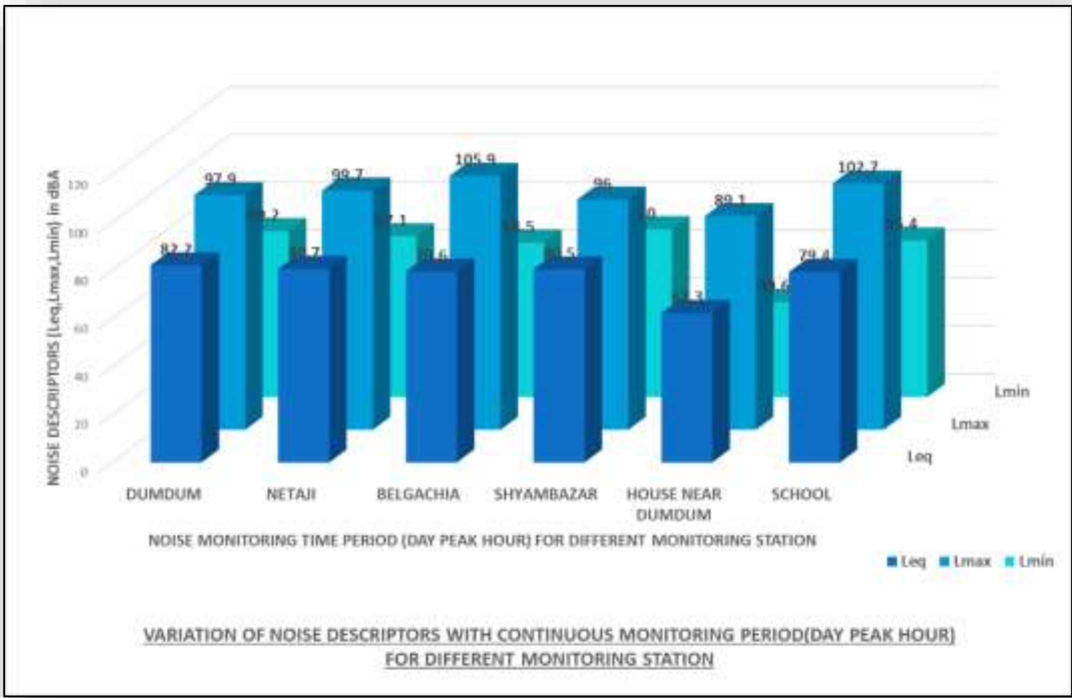
Table-5.6: Descriptive statistical data of Noise of Residential Building

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	56.00	57.80	54.20	2.55	4.55
L_{max}	85.40	86.80	84.00	1.98	2.32
L_{min}	42.75	45.90	39.60	4.45	10.42
L_1	67.70	69.90	65.50	3.11	4.60
L_{10}	56.05	56.40	55.70	0.49	0.88
L_{50}	48.90	49.60	48.20	0.99	2.02
L_{90}	46.15	47.90	44.40	2.47	5.36
L_{99}	44.60	47.10	42.10	3.54	7.93
NC	9.90	11.30	8.50	1.98	20.00
TNI	55.75	59.60	51.90	5.44	9.77

From above table it may be concluded that maximum and minimum value of L_{eq} were 57.80 dB(A) and 54.20 dB(A). Mean value of L_{eq} was 56.00±2.55 dB(A). These values of L_{eq} did not exceed the respective CPCB standards i.e., 65 dB(A) for day time and 55 dB(A) for night time for commercial area.
TNI has its mean value of 55.75 ± 5.44 dB(A) which is lesser than the 74 dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is less annoying to the commuters.
In this case coefficient of variation of L_{eq} was calculated 20.73%.

5.2.2 Continuous noise monitoring at different monitoring station for Kolkata Metro Railway System

In this present study, noise due to Kolkata Metro Railway was monitored at different noise influenced stations over the period of two hours at different periods (Peak hour & Non-peak hour) at day and night hours. This type of continuous noise monitoring is necessary for investigation of average noise at each noise monitoring station.



VARIATION OF NOISE DESCRIPTORS WITH CONTINUOUS MONITORING PERIOD(DAY PEAK HOUR) FOR DIFFERENT MONITORING STATION

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Fig-5.3: Variation of noise descriptors (L_{eq}, L_{max} and L_{min}) in dB(A) for continuous monitoring at different monitoring stations at Day Peak Hour with respect to monitoring period

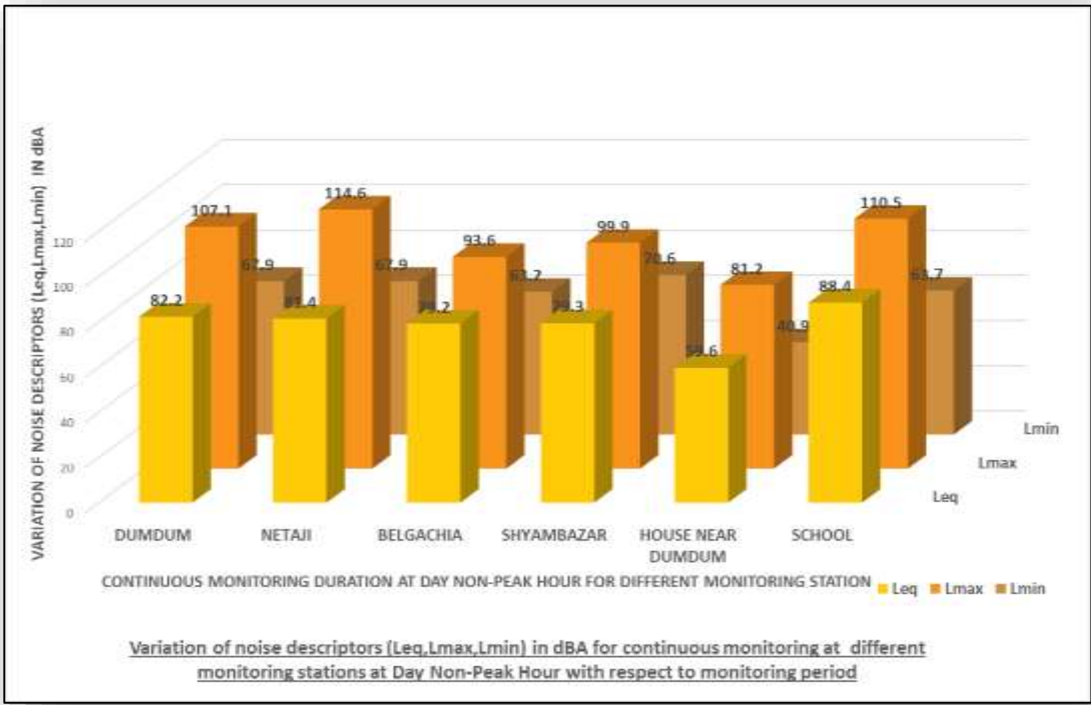


Fig-5.4: Variation of noise descriptors (L_{eq}, L_{max} and L_{min}) in dB(A) for continuous monitoring at different monitoring stations at Day Non-Peak Hour with respect to monitoring period

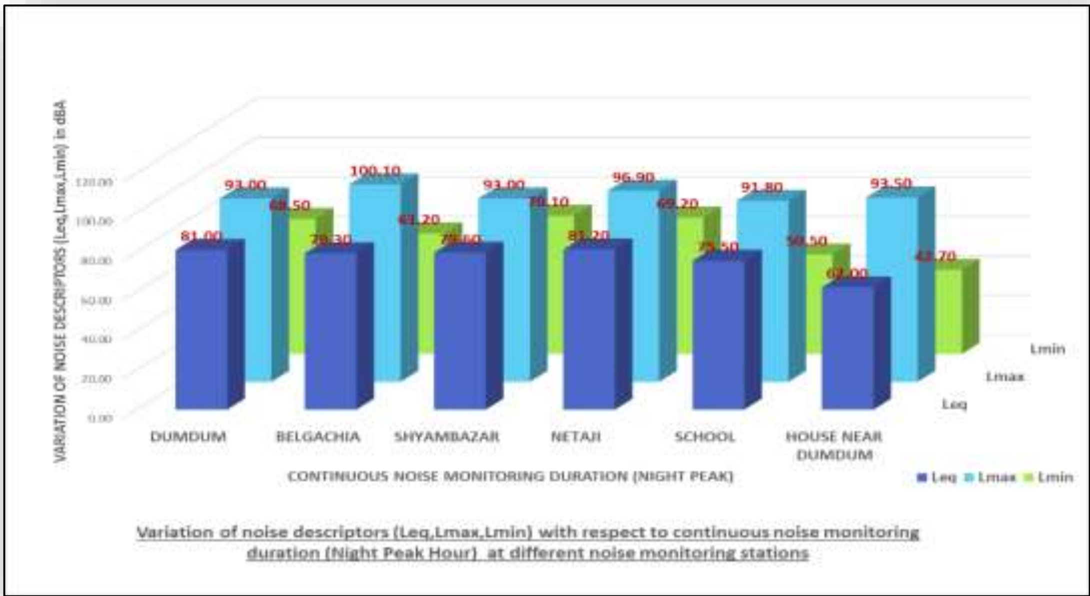


Fig-5.5: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) for continuous monitoring at different monitoring stations at Night Peak Hour with respect to monitoring period

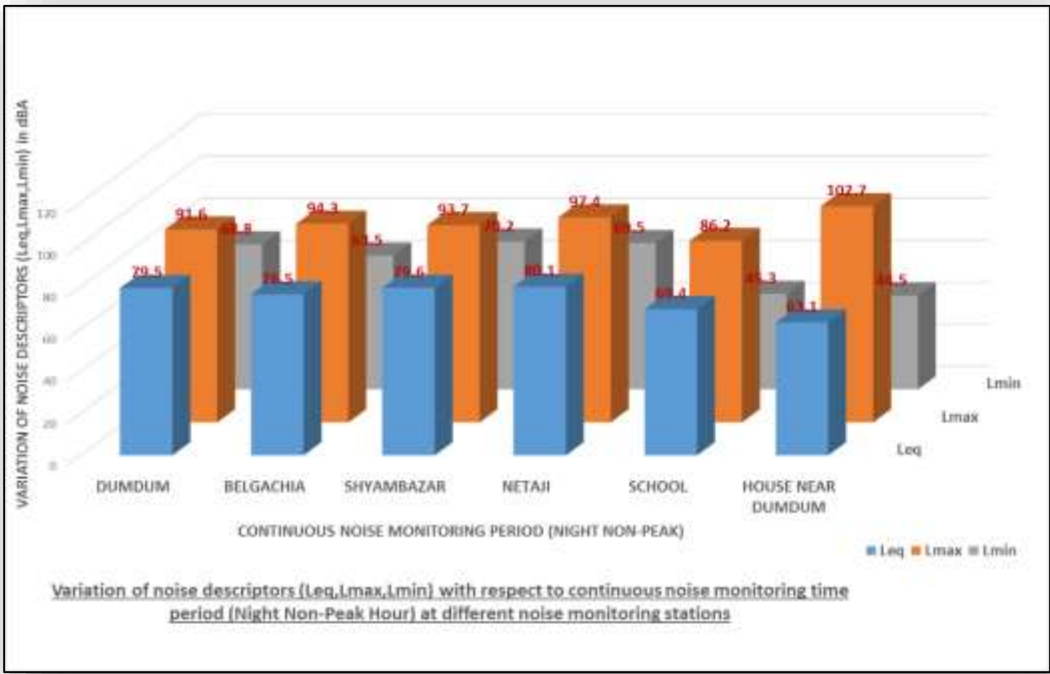


Fig-5.6: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) for continuous monitoring at different monitoring stations at Night Non-Peak Hour with respect to monitoring period

From these sets of data average noise exposures for a commuter or worker associated with metro railway noise can be computed.

Present study pointed out the sources of these average noise with varying operational frequencies of metro stations both underground and overground at different monitoring hour (day peak, day non-peak, night peak and night non-peak) were as follows:

For underground stations (Belgachia and Shyambazar), average A-weighted noise level were developed due to metro rakes (AC & Non-AC) (which includes compressor noise, rail-wheel interaction, braking operation noise, door operation noise, train whistle noise , during rake's movement whooshing noise etc.) , advertisement TV, intermittent announcement made by metro authority, blowing of whistles by RPF for making passengers alert to the metro arrival and departure, conversation between the passengers, rattling of the ceiling panels, ventilation system, electrical gadgets etc. To some extent, the noise was contributed by electrical substation (receiving 6KV power from CESC) situated at Belgachia Metro Station and (33KV power from CESC) situated at Shyambazar Metro Station.

In the case of overground station (Dumdum and Netaji) average A-weighted noise level were developed due to metro rakes (AC & Non-AC) (which includes compressor noise, rail-wheel interaction, braking operation noise, door operation noise, train whistle noise , during rake's movement whooshing noise etc.), advertisement TV, intermittent announcement made by metro authority, blowing of whistles by RPF for making passengers alert to the metro arrival and departure, conversation between the passengers, high sweeping noise from fan's fitted at station, other outside traffic noise (specially for Dumdum Metro station nearby EMU and other train noise moving on rail track with ballast and for Netaji Metro station outside vehicular traffic noise) etc.

Daily exposure to these high noise level may lead a person to permanent hearing disorders and several other health problems.

5.2.2.1 Discussion on Continuous Noise Monitoring data for Dumdum Metro Railway Station

Dumdum Metro Railway station is reasonably affected by **metro railway** noise and as well as by nearby **EMU** noise. That is why to determine average noise at station platform, continuous noise monitoring was conducted at middle position of **Dumdum Metro Railway** station platform at different commercial hours.

5.2.2.1.1 Noise monitoring at Day Commercial Hour

- **Continuous noise monitoring at Day Peak hour**

The day peak hour average noise observed over two hours of monitoring at passenger's ear level was 82.2 dB(A) (Fig-5.3).

- **Continuous noise monitoring at Day Non-Peak hour**

The day non-peak hour average noise observed over two hours of monitoring at passenger's ear level was 82.2 dB(A) (Fig-5.4) same as the noise of day peak hour.

Daily exposure by this high noise level for a passenger or worker may led to permanent hearing disorder and others health disease.

5.2.2.1.2 Noise monitoring at night commercial hour

- **Continuous noise monitoring at Night Peak hour**

In the case of night peak hour A-weighted average noise measured over two hours of monitoring period at passenger's ear level at Dumdum Metro Station was 81.0 dB(A).

- **Continuous noise monitoring at Night Non-Peak hour**

During night non-peak hour frequency of metro rakes was little bit less than that of peak hour, and consequently the noise level observed over two hours monitoring period at passenger's ear level at night non-peak hour was 79.5 dB(A).

Table-5.7: Descriptive statistical data of average noise of Dumdum Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
n	10.50	14.00	7.00	2.89	27.49
L_{eq}	81.23	82.20	79.50	1.28	1.58
L_{max}	97.40	107.10	91.60	7.01	7.20
L_{min}	68.60	69.20	67.90	0.55	0.80
L_1	88.55	90.90	87.00	1.67	1.89
L_{10}	84.53	85.60	82.90	1.15	1.36
L_{50}	78.90	81.10	76.90	2.26	2.87
L_{90}	73.43	74.10	73.00	0.47	0.64
L_{99}	70.85	71.30	70.60	0.31	0.44
NC	11.10	12.30	9.60	1.24	11.13
TNI	87.83	92.50	81.70	4.79	5.45

From above table, it may be concluded that maximum and minimum value of L_{eq} were 82.20 dB(A) and 79.50 dB(A). Mean value of L_{eq} was 81.23±1.28 dB(A).
This mean value of L_{eq} 81.23 dB(A) exceeds the CPCB standards i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.
TNI has its mean value of 87.83 ±4.79 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is reasonably annoying to the commuters.
In this case coefficient of variation of number of rakes (n) was 27.49%, which is higher than coefficient of variation of L_{eq}, 1.58%, which means noise level did not vary much with the variation of number of rakes.

From, correlation matrix of noise data generated from continuous monitoring at Dumdum Metro Railway Station (Annex Table-1) at different hours it is revealed that:

i) High positive correlation exists between number of rakes (n) and L_1(p=0.961). Linear relationship exists between number of rakes (n) and L_1. It signifies that L_1increases with the increase in number of rakes (n).
ii) High positive correlation (p=0.955) exists between L_{10} and TNI. Linear relationship exists between TNI and L_{10}. It signifies that TNI increases with the increase in L_{10}.
iii) Very high correlation (p=0.996) exists between TNI and noise climate (NC). That means TNI can be replaced by NC.

5.2.2.2 Discussion on Continuous Noise Monitoring data for Netaji Metro Railway Station

Netaji Metro Railway station is verily affected by **metro railway** noise and as well as outside traffic noise. That is why to determine average noise at station platform, continuous noise monitoring was conducted at middle position of **Netaji Metro Railway** station platform (here it was at middle of the down platform) at different commercial hour of **Kolkata Metro Railway**.

5.2.2.2.1 Noise monitoring at day commercial hour

- **Continuous noise monitoring at Day Peak hour**

At day peak hour average noise was observed over two hours of monitoring at passenger's ear level was 80.7 dB(A) (Fig-5.3).

- **Continuous noise monitoring at Day Non-Peak hour**

At day non-peak hour average noise was recorded over two hours of monitoring at passenger's ear level was 81.4 dB(A) (Fig-5.4).

5.2.2.2.2 Noise monitoring at night commercial hour

- **Continuous noise monitoring at Night Peak hour**

In the case of night peak hour, A-weighted average noise was measured over two hours of monitoring period at passenger's ear level at Netaji Metro Station was 81.2 dB(A).

- **Continuous noise monitoring at Night Non-Peak hour**

During night non-peak hour frequency of metro rakes was reduced than peak hour, therefore, the observed noise level over two hours monitoring period at passenger's ear level at night non-peak hour was 80.1 dB(A).

Table-5.8: Descriptive statistical data of average noise of Netaji Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
n	9.75	12.00	8.00	2.06	21.14
L_{eq}	80.85	81.40	80.10	0.58	0.72
L_{max}	102.15	114.60	96.90	8.39	8.21
L_{min}	68.43	69.50	67.10	1.12	1.64
L_1	90.33	90.70	90.00	0.33	0.37
L_{10}	84.70	85.30	83.90	0.58	0.69
L_{50}	75.60	76.80	74.90	0.88	1.16
L_{90}	71.83	72.60	71.10	0.61	0.85
L_{99}	70.13	70.20	70.00	0.10	0.14
NC	12.88	13.00	12.70	0.15	1.17
TNI	93.33	93.80	92.30	0.71	0.76

From above table it may be concluded that maximum and minimum value of L_{eq} were 81.40 dB(A) and 80.10 dB(A). Mean value of L_{eq} was 80.85±0.58 dB(A).
This mean value of L_{eq} (80.85 dB (A)) exceeds the CPCB standards for L_{eq}, i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.
TNI has its mean value of 93.33 ±0.71 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is reasonably annoying to the passengers and workers.
In this case coefficient of variation of number of rakes (n) was 21.14%, which is higher than coefficient of variation of L_{eq}, 0.72%, which means noise level did not vary much with the variation in the number of rakes.
The correlation matrix of noise data generated from continuous monitoring at Netaji Metro Railway Station (Annex Table-2) at different hours reveals that:

i) Very high positive statistically significant correlation exists between L_{eq} and L_{max} (p=0.975). Linear proportional relationship exists between L_{eq} and L_{max}. It signifies that L_{eq} increases with the increase in L_{max}.

ii) Very high positive statistically significant correlation (p=0.979) exists between L_{eq} and L_{10}. Linear proportional relationship exists between L_{eq} and L_{10}. It signifies that L_{eq} increases with the increase in L_{10}.
iii) Very high positive statistically significant correlation (p=0.996) exists between L_{max} and L_{10}. That means strong linear proportional relationship exists between these two.
iv) Very high positive statistically significant correlation exists between L_{max} and L_{50} (p=0.975). Linear proportional relationship exists between L_{max} and L_{50} (Median Noise). It signifies that L_{max} increases with the increase in median noise (L_{50}).
v) Very high positive statistically significant correlation exists between L_{min} and L_{50} (p=0.971). Linear proportional relationship exists between L_{min} and L_{50} (Median Noise). It signifies that L_{min} increases with the increase in median noise (L_{50}).
vi) Very high positive statistically significant correlation (p=1) exists between L_{min} and L_{90}. That means strong linear proportional relationship exists between these two. Therefore, L_{min} was influenced by background noise.
vii) Very high positive statistically significant correlation (p=0.998) exists between L_{min} and L_{99}. That means strong linear proportional relationship exists between these two and this L_{min} was influenced by very background noise.
viii) Very high positive statistically significant correlation exists between L_{10} and L_{50}(p=0.983). Linear proportional relationship exists between L_{10} and L_{50} (Median Noise). It signifies that peak noise (L_{10}) was influenced by median noise (L_{50}).
ix) Very high positive statistically significant correlation exists between L_{50} and L_{90} (p=0.968). Linear proportional relationship exists between L_{50} (median noise) and L_{90} (background noise). It signifies that median noise (L_{50}) was influenced by background noise (L_{90}).
x) Very high positive statistically significant correlation exists between L_{50} and L_{99}(p=0.956). Linear proportional relationship exists between L_{50} (median noise) and L_{99}(very background noise). It signifies that median noise (L_{50}) was influenced by very background noise (L_{99}).
xi) Very high positive statistically significant correlation exists between L_{90} and L_{99} (p=0.999). Linear proportional relationship exists between L_{90} (background noise) and L_{99} (very background noise). It signifies that background noise (L_{90}) was influenced by very background noise (L_{99}).
xii) Very high positive statistically significant correlation exists between L_1 and TNI (p=0.998). Linear proportional relationship exists between L_1 (peak noise) and TNI. It signifies that TNI is highly influenced by peak noise (L_1).

5.2.2.3 Discussion on Continuous Noise Monitoring data for Belgachia Metro Railway Station

Belgachia Metro Railway station is one of the overcrowded underground metro station, which is considerably affected by **metro railway** noise and other noise associated with this station functioning. Consequently, to determine average noise at this station platform, continuous noise monitoring was conducted at middle position of **Belgachia Metro Railway** station platform over the period of two hours at different commercial hours of **Kolkata Metro Railway**.

5.2.2.3.1 Noise monitoring at day commercial hour

- **Continuous noise monitoring at Day Peak hour**

At day peak hour average noise was observed over two hours of monitoring at passenger's ear level was 79.6 dB(A) (Fig-5.3).

- **Continuous noise monitoring at Day Non-Peak hour**

At day non-peak hour average noise was recorded over two hours of monitoring at passenger's ear level was 79.2 dB(A) (Fig-5.4).

5.2.2.2.2 Noise monitoring at night commercial hour

- **Continuous noise monitoring at Night Peak hour**

In the case of night peak hour A-weighted average noise was measured over two hours of monitoring period at passenger's ear level at Belgachia Metro Station was 79.3 dB(A).

- **Continuous noise monitoring at Night Non-Peak hour**

During night non-peak hour frequency of metro rakes was reduced than peak hour, therefore, the observed noise level over two hours monitoring period at passenger's ear level at night non-peak hour was 76.5 dB(A).

Table-5.9: Descriptive statistical data of average noise of Belgachia Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
n	9.25	12.00	5.00	3.40	36.79
L_{eq}	78.65	79.60	76.50	1.44	1.84
L_{max}	98.48	105.90	93.60	5.74	5.83
L_{min}	63.10	64.50	61.20	1.38	2.19
L_1	88.85	90.00	87.60	0.99	1.12
L_{10}	83.35	86.70	80.10	2.70	3.23
L_{50}	72.40	73.50	70.70	1.22	1.68
L_{90}	67.28	67.90	67.00	0.43	0.64
L_{99}	64.90	65.90	63.40	1.10	1.69
NC	16.08	18.80	13.10	2.33	14.51
TNI	101.58	113.10	89.40	9.69	9.54

From above table it may be concluded that maximum and minimum value of L_{eq} were 79.60 dB(A) and 76.50 dB(A) respectively. Mean value of L_{eq} was 78.65±1.44 dB(A).

This mean value of L_{eq} (78.65 dB (A)) exceeds the CPCB standards for L_{eq} i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 101.58 ±9.69 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the passengers and workers.

In this case coefficient of variation of number of rakes (n) was 36.79%, which is higher than coefficient of variation of L_{eq}, 1.84%, that means noise level did not vary much with the variation in the number of rakes.

The correlation matrix of noise data generated from continuous monitoring at Belgachia Metro Railway Station (Annex Table-3) at different hours reveals that:

i) Very high positive statistically significant correlation exists between L_1 and L_{10} (p=0.983). Linear proportional relationship exists between L_1 (Very Peak Noise) and L_{10} (Peak Noise). It signifies that very peak noise (L_1) was influenced by peak noise (L_{10}).

ii) Very high positive statistically significant correlation exists between L_{99} and L_{min} (p=0.983). Linear proportional relationship exists between L_{99} (Very Background Noise) and $L_{min.}$ It signifies that very background noise (L_{99}) was influenced by $L_{min.}$

iii) Very high positive statistically significant correlation exists between L_1 and noise climate (NC) (p=0.980). Linear proportional relationship exists between

L_1 (very peak noise) and NC. It signifies that very peak noise (L_1) was influenced by NC.

iv) Very high positive statistically significant correlation exists between L_{10} and noise climate (NC) (p=0.996). Linear proportional relationship exists between L_{10} (very peak noise) and NC. It signifies that peak noise (L_{10}) was highly influenced by NC.

v) Very high positive statistically significant correlation exists between L_1 and traffic noise index (TNI) (p=0.982). Linear proportional relationship exists between L_1 (very peak noise) and TNI. It signifies that very peak noise (L_1) was influenced by TNI.

vi) Very high positive statistically significant correlation exists between L_{10} and traffic noise index (TNI) (p=0.998). Linear proportional relationship exists between L_{10}(peak noise) and TNI. It signifies that peak noise (L_{10}) was verily influenced by TNI.

vii) Very high positive statistically significant correlation exists between noise climate (NC) and traffic noise index (TNI) (p=1). Linear proportional relationship exists between NC and TNI. It signifies that NC was verily influenced by TNI.

5.2.2.4 Discussion on Continuous Noise Monitoring data for Shyambazar Metro Railway Station

Shyambazar Metro Railway station is one of the overcrowded underground metro station situated in the heart of North Kolkata, which is extremely affected by **metro railway** noise and other noise associated with this station operation. Consequently, to determine average noise at this underground continuous noise monitoring was conducted at middle position of **Shyambazar Metro Railway** station platform over the period of two hours at different commercial hours of **Kolkata Metro Railway** station platform.

5.2.2.4.1 Noise monitoring at day commercial hour

- **Continuous noise monitoring at Day Peak hour**

At day peak hour average noise was observed over two hours of monitoring at passenger's ear level was 80.5 dB(A) (Fig:5.3).

- **Continuous noise monitoring at Day Non-Peak hour**

At day non-peak hour average noise was recorded over two hours of monitoring at passenger's ear level was 79.3 dB(A) (Fig:5.4).

5.2.2.4.2 Noise monitoring at night commercial hour

- **Continuous noise monitoring at Night Peak hour**

In the case of night peak hour A-weighted average noise was measured over two hours of monitoring period at passenger's ear level at Shyambazar Metro Station was 79.6 dB(A).

- **Continuous noise monitoring at Night Non-Peak hour**

During night non-peak hour, frequency of metro rakes reduces significantly as compared to peak hour. Therefore, the observed noise level over two hours monitoring period at passenger's ear level at night non-peak hour was 76.6 dB(A).

Table-5.10: Descriptive statistical data of average noise of Shyambazar Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
n	10.50	12.00	8.00	1.91	18.24
L_{eq}	79.75	80.50	79.30	0.52	0.65
L_{max}	95.65	99.90	93.00	3.11	3.25
L_{min}	70.23	70.60	70.00	0.26	0.37
L_1	88.68	89.00	88.40	0.28	0.31
L_{10}	83.25	84.30	82.40	0.79	0.94
L_{50}	76.58	77.40	76.20	0.57	0.74
L_{90}	72.58	73.00	72.40	0.29	0.40
L_{99}	71.25	71.40	71.20	0.10	0.14
NC	10.68	11.30	9.90	0.58	5.43
TNI	85.28	88.20	82.10	2.50	2.93

From above table it may be concluded that maximum and minimum value of L_{eq} were 80.50 dB(A) and 79.30 dB(A) respectively. Mean value of L_{eq} was 79.75±0.52 dB(A).

This mean value of L_{eq} (79.75 dB (A)) exceed the CPCB standard for L_{eq} , i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 85.28 ± 2.50 dB(A) which is higher than the 74 dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the passengers and workers.

In this case coefficient of variation of number of rakes (n) was 18.24%, which is higher than the coefficient of variation of L_{eq}, i.e. 0.65%, which means noise level did not vary much with the variation of number of rakes.

From the correlation matrix of noise data generated from continuous monitoring at Shyambazar Metro Railway Station (Annex Table-4) at different hours it reveals the fact that:

i) Very high statistically significant positive correlation exists between L_{eq} and L_{10} (p=0.980). Linear proportional relationship exists between L_{eq} and L_{10} (Peak Noise). It signifies that equivalent noise (L_{eq}) was influenced by peak noise (L_{10}).

ii) Very high statistically significant positive correlation exists between L_{eq} and L_{50} (p=0.966). Linear proportional relationship exists between L_{eq} and L_{50}. It signifies that equivalent noise (L_{eq}) was influenced by median noise (L_{50}).

iii) Very high statistically significant positive correlation exists between L_{min} and L_{99} (p=0.951). Linear proportional relationship exists between L_1 (very peak noise) and L_{99} (very background noise). It signifies that very peak noise (L_1) was influenced byL_{99} (very background noise).

iv) Very high statistically significant negative correlation exists between L_{min} and noise climate (NC) (p=-0.957). Inversely proportional relationship exists between L_{min} (very peak noise) and NC. It signifies that L_{min} was increased with decreasing in NC.

v) Very high statistically significant positive correlation exists between L_{10} and noise climate (NC) (p=0.956). Linear proportional relationship exists between L_{10}(peak noise) and NC. It signifies that NC was influenced by peak noise (L_{10}).

vi) Very high statistically significant positive correlation exists between L_{10} and traffic noise index (TNI) (p=0.979). Linear proportional relationship exists between L_{10} (peak noise) and TNI. It signifies that TNI was influenced by L_{10}.

vii) Very high statistically significant positive correlation exists between noise climate (NC) and traffic noise index (TNI) (p=0.996). Linear proportional relationship exists between noise climate (NC) and traffic noise index (TNI). It signifies that increase in noise climate causes the increase in traffic noise index (TNI).

5.2.2.5 Discussion on Continuous Noise Monitoring data for School building (Swami Pranabananda Vidyapith) (near Netaji Metro) noise heavily exposed by metro noise

Under the purview of present study, continuous noise monitoring was conducted **at Swami Pranabananda Vidyapith** near **Netaji Metro Station,** which is extremely exposed to over-ground metro railway noise. The objective of this phase of the study was to assess the effect of metro railway noise on commercial building close to the metro track. There are three piers of extended over-ground metro track, which lie within the school premises. Thus the over-ground metro track is too close to school building. Due this reason teachers and students are exposed to high level continuous noise during school hours, which may become detrimental for their health.

This study was conducted at different hour in a day, at first floor level of that school building.

Major noise producing sources (varying operational frequency) of that school buildings at different noise monitoring hour(day peak, day non-peak, night peak and night non-peak) were, passing metro rakes (AC & Non-AC) through adjacent metro track(for all monitoring hour), conversation and activities of students and staffs, sound of bell to make different operational alert to workers and students, collective prayer of students and vehicular movement outside the school etc. at day peak and day non-peak hour.

At night peak and night non-peak hour apart from moving metro rakes (AC and Non-AC) (with varying operational frequency) other noise producing sources were, religious activities at the adjacent temple, bird's noise and vehicular movements and human activities outside the premises etc.

Long term exposure of this high level of noise may make adverse impact on the health of students and staffs of that school.

5.2.2.5.1 Noise monitoring at day commercial hour

- **Continuous noise monitoring at Day Peak hour**

During day peak hour, noise quality was monitored over a period of two hours at first floor level and the mean L_{eq} was observed as 79.4 dB(A) (Fig-5.3).

- **Continuous noise monitoring at Day Non-Peak hour**

During day non-peak hour, noise quality was monitored over a period of two hours at first floor level and the mean L_{eq} was observed as 88.4 dB(A) (Fig-5.4).

5.2.2.5.2 Noise monitoring at night commercial hour

- **Continuous noise monitoring at Night Peak hour**

During night peak hour, noise quality was monitored over a period of two hours at first floor level and the mean L_{eq} was observed as 75.5 dB(A) (Fig-5.5).

➢ **Continuous noise monitoring at Night Non-Peak hour**

During night peak hour, noise quality was monitored over a period of two hours at first floor level and the mean L_{eq} was observed as 69.4 dB(A) (Fig-5.6).

Table-5.11: Descriptive statistical data for average noise of a School building (Swami Pranabananda Vidyapith) (near Netaji Metro) heavily exposed to metro noise

	MEAN	MAX	MIN	STDEV	%CV
n	10.50	16.00	7.00	4.04	38.49
L_{eq}	78.18	88.40	69.40	7.96	10.19
L_{max}	97.80	110.50	86.20	10.89	11.14
L_{min}	56.23	65.40	45.30	9.87	17.55
L_1	89.53	98.30	84.00	6.17	6.89
L_{10}	76.30	91.70	60.60	13.62	17.86
L_{50}	66.85	83.80	50.00	16.25	24.30
L_{90}	61.03	72.90	47.60	12.43	20.37
L_{99}	58.18	68.70	46.50	10.59	18.20
NC	15.28	21.50	9.60	5.14	33.62
TNI	92.13	126.20	69.60	24.40	26.49

From above table it may be concluded that maximum and minimum value of L_{eq} were 88.40 dB(A) and 69.40 dB(A) respectively. Mean value of L_{eq} was 78.18±7.96 dB(A).

This mean value of L_{eq} (78.18 dB (A)) exceeds the CPCB standards for L_{eq} i.e. 50 dB(A) for day time and 40 dB(A) for night time for silence zone (100 meters from educational institution).

TNI has its mean value of 92.13 ±24.40 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is by and large annoying to the students and workers.

In this case coefficient of variation of number of rakes (n) was 38.49%, which is higher than coefficient of variation of L_{eq}, i.e. 10.19%, which means noise level did not vary much with the variation of number of rakes.

From, correlation matrix (Annex Table-5) of average noise data generated from continuous monitoring at the school building (Swami Pranabananda Vidyapith) near Netaji Metro, heavily exposed to metro noise at different hours, it is revealed that:

i) Very high statistically significant positive correlation exists between L_{eq} and L_{max} (p=0.975). Linear proportional relationship exists between L_{eq} and L_{max}. It signifies that equivalent noise (L_{eq}) was influenced by L_{max}.

ii) Very high statistically significant positive correlation exists between L_{eq} and L_{10} (p=0.979). Linear proportional relationship exists between L_{eq} and L_{10}. It signifies that equivalent noise (L_{eq}) was influenced by peak noise (L_{10}).

iii) Very high statistically significant positive correlation exists between L_{max} and L_{10} (p=0.996). Linear proportional relationship exists between L_{max} and L_{10} (peak noise). It signifies that L_{max} was influenced by L_{10} (peak noise).

iv) Very high statistically significant positive correlation exists between L_{max} and L_{50} (p=0.990). Linear proportional relationship exists between L_{max} and L_{50}. It signifies that L_{max} was increased with increasing inL_{50}.

v) Very high statistically significant positive correlation exists between L_{min} and L_{50} (p=0.971). Linear proportional relationship exists between L_{min} and L_{50}.It signifies that L_{min} was influenced by median noise (L_{50}).

vi) Very high statistically significant positive correlation exists between L_{min} and L_{90} (p=1). Linear proportional relationship exists between L_{min} and L_{90}.It signifies that L_{min} was influenced by L_{90}.

vii) Very high statistically significant positive correlation exists between L_{min} and L_{99} (p=0.998). Linear proportional relationship exists between L_{min} and L_{99}. It signifies that increase in L_{min} causes the increase in L_{99}.

viii) Very high statistically significant positive correlation exists L_1 between TNI between (p=0.998). Linear proportional relationship exists between L_1 and TNI. It signifies that increase in L_1 causes the increase in TNI.

ix) Very high statistically significant positive correlation exists L_{10} between L_{50} between (p=0.983). Linear proportional relationship exists between L_{10} and L_{50}. It signifies that increase in peak noise L_{10} causes the increase in median noise L_{50}.

x) Very high statistically significant positive correlation exists L_{50} between L_{90} between (p=0.968). Linear proportional relationship exists between L_{50} and L_{90}. It signifies that increase in background noise L_{90} causes the increase in median noise L_{50}.

xi) Very high statistically significant positive correlation exists L_{50} between L_{99} between (p=0.956). Linear proportional relationship exists between L_{50} and L_{99}. It signifies that increase in very background noise L_{99} causes the increase in median noise L_{50}.

xii) Very high statistically significant positive correlation exists L_{90} between L_{99} between (p=0.999). Linear proportional relationship exists between L_{90} and L_{99}. It signifies that there is no such difference between background noise L_{90} and very background noise L_{99}.

5.2.2.6 Discussion on Continuous Noise Monitoring data for a residential building (near Dumdum Metro Station) noise heavily exposed by metro noise

In this present study, continuous noise monitoring was conducted at a residential building near **Dumdum Metro Station,** which is extremely exposed to metro railway noise, as well as EMU or other kind of train noise, to assess the effect of metro railway noise on residential building close to the metro track. Due this reason continuous exposure to metro railway noise on residents (different ages) are too high and it may become detrimental for their health.

This study was conducted at different hours in a day, at 2nd floor level of that residential building.

In the present study it was observed that major noise sources (with varying frequency) for that residential building near Dumdum Metro station at different monitoring hours are metro rakes (AC and Non-AC), movement of EMU and other types of trains on the track with ballast near Dumdum Metro station, resident's conversation and activities and bird's noise from outside etc.

Continuous exposure to this high noise level may make adverse impact on residents.

5.2.2.6.1 Noise monitoring at day commercial hour

- **Continuous noise monitoring at Day Peak hour**

At day peak hour average noise was observed over two hours of monitoring at 2^{nd} floor level and it came out to be **62.3 dB(A)** (Fig-5.3).

- **Continuous noise monitoring at Day Non-Peak hour**

At day peak hour average noise was observed over two hours of monitoring at 2^{nd} floor level and it came out to be **59.6 dB(A)** (Fig-5.4).

5.2.2.6.2 Noise monitoring at day commercial hour

- **Continuous noise monitoring at Night Peak hour**

At night peak hour average noise was observed over two hours of monitoring at 2^{nd} floor level and it came out to be **62.0 dB(A)** (Fig-5.5).

- **Continuous noise monitoring at Night Non-Peak hour**

At night non-peak hour average noise was observed over two hours of monitoring at 2nd floor level and it came out to be **63.1 dB(A)** (Fig-5.6).

Table-5.12: Descriptive statistical data of average noise of residential building (near Dumdum Metro Station) heavily exposed to metro and EMU noise

	MEAN	MAX	MIN	STDEV	%CV
n	10.50	12.00	8.00	1.91	18.24
L_{eq}	61.75	63.10	59.60	1.51	2.44
L_{max}	91.63	102.70	81.20	8.97	9.79
L_{min}	41.93	44.50	39.60	2.14	5.09
L_1	71.08	72.10	70.60	0.69	0.97
L_{10}	63.10	64.50	61.90	1.10	1.74
L_{50}	51.45	52.30	50.50	0.74	1.44
L_{90}	45.90	47.90	43.70	1.73	3.76
L_{99}	43.85	46.30	41.40	2.02	4.61
NC	17.20	20.80	14.80	2.58	14.99
TNI	84.70	96.90	77.10	8.70	10.27

From above table it is observed that maximum and minimum value of L_{eq} were 63.10 dB(A) and 59.60 dB(A) respectively. Mean value of L_{eq} was 61.75±1.51 dB(A).

This mean value of L_{eq} (61.75 dB (A)) exceeds the CPCB prescribed value of L_{eq} i.e. 55 dB(A) for day time and 45 dB(A) for night time for residential area.

TNI has its mean value of 84.70 ± 8.70 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the residents.

In this case coefficient of variation of number of rakes (n) was 18.24%, which is higher than coefficient of variation of L_{eq}, 2.44%, that means noise level did not vary much with the variation of number of rakes.

From, correlation matrix of average noise data generated from continuous monitoring at residential building (Annex Table-6) (near Dumdum Metro Railway Station) heavily exposed to metro noise and EMU noise at different hours it is revealed that:

i) Very high statistically significant positive correlation exists between L_{min} and L_{99} (p=0.976). Linear proportional relationship exists between L_{min} and L_{99} .It signifies that L_{min} was influenced by L_{99}.
ii) Very high statistically significant positive correlation exists between L_{90} and L_{99} (p=0.970). Linear proportional relationship exists between L_{90} and L_{99}. It signifies that there was no such difference between background noise (L_{90}) and very background noise (L_{99}).
iii) Very high statistically significant negative correlation exists between L_{99} and NC (p=-0.963). Inversely proportional relationship exists between L_{99} and NC. It signifies that increase in L_{99} may cause the decrease in NC.
iv) Very high statistically significant positive correlation exists between NC and TNI (p= 0.998). Linear proportional relationship exists between NC and TNI. It signifies that TNI was increased with increasing in NC.

5.2.3 Instantaneous noise data of different noise monitoring station

To investigate the boost of average noise level due to arrival and departure of metro rakes, separate noise measurement was conducted during the period between metro rakes arrival and departure at those noise monitoring stations during different commercial hours of Kolkata Metro Railway.

This arrival and departure of metro rakes at metro station raised the ambient noise level of the station (both overground and underground) by a large decibel value.

The sources of that momentary noise were primarily metro rakes (AC and Non-AC rake). Area of noise sources within a moving and idling metro rakes (AC and Non-AC rake) were, wheel-rail contact, braking noise, compressor and ventilation system noise, door operational noise, honking of train horn, public address system when door of the rakes open and close etc. Besides, these rake's noise other types of average platform noise (advertisement TV, intermittent announcement made by metro authority, blowing of whistles by RPF for making passengers alert to the metro arrival and departure, conversation between the passengers, rattling of the ceiling panels, ventilation system, electrical gadgets) were there for underground stations and in overground stations average platform noise excluding rattling of ceiling panels, ventilation system as noise source others were same as underground station.

In addition, with this above-mentioned noise, sweeping of fans, outside traffic and bird's noise were responsible for some added noise in the case of overground metro stations.
Operational frequency of some of these noise source was varied with different monitoring hours.

5.2.3.1 Instantaneous noise data of Dumdum Metro Railway Station:

Although, nowadays Kolkata Metro Railway operation is being conducted in between Noapara Metro Railway Station and Kavi Subhash Metro Railway Station, most of the time Dumdum Metro Railway Station acts as terminal station. Therefore, operation of many metro rakes (AC/Non-AC) is being conducted from Dumdum Metro Railway Station. Consequently, this station suffers extremely from high noise level of metro rakes and sometimes from nearby EMU train noise, express train noise and goods train noise etc.

- **Instantaneous noise data at day peak hour**

At day peak hour frequency of metro rake is too high, almost at 5.0 mins interval. The study was focused on individual noise generated by AC and Non-AC rakes and it also took into account the noise generated by combined movement of of AC and Non-AC rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).

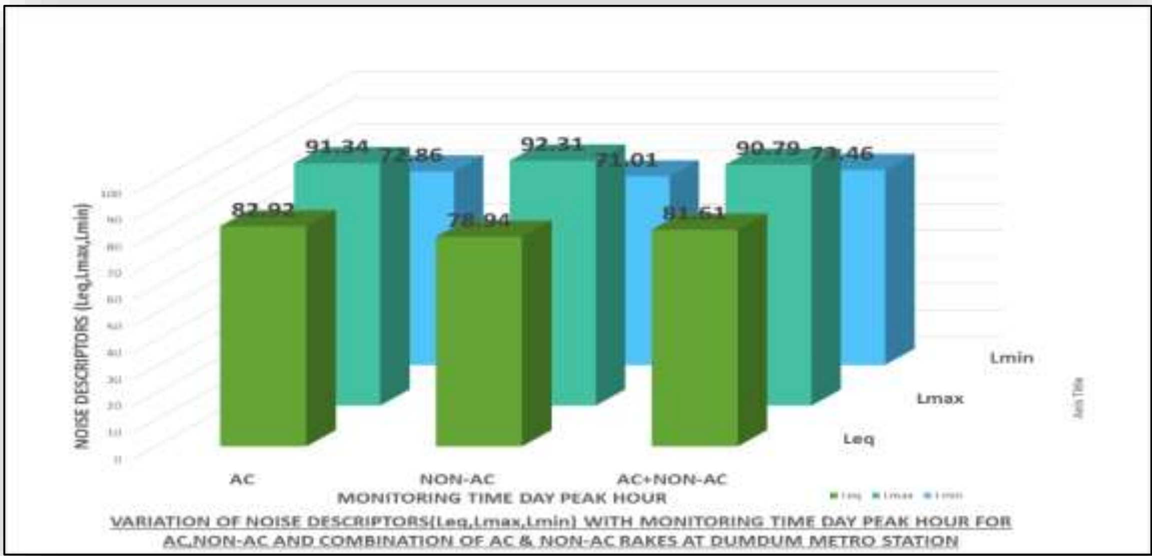


Fig-5.7: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time day peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Dumdum Metro Station

• From Fig-5.7, it is observed that equivalent noise level was maximum **(81.61 dB(A))** in the case of noise due to simultaneous movement of AC and Non-AC rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).
• In the case of AC rakes, equivalent noise level was measured as **(82.92 dB(A))** during the period of arrival, resting at the platform and departure from the platform.
• In the case of Non-AC rakes, equivalent noise level was measured as **(78.94 dB(A))** during the period of arrival, resting at platform and departure from platform.

➢ **Instantaneous noise data at day non-peak hour**

At day non-peak hour frequency of metro rakes was less. Due to this less frequency of metro rail, noise generated was little bit less. But, in some cases for long time standing of metro rakes at platform was responsible for enhancement of average noise of platform.

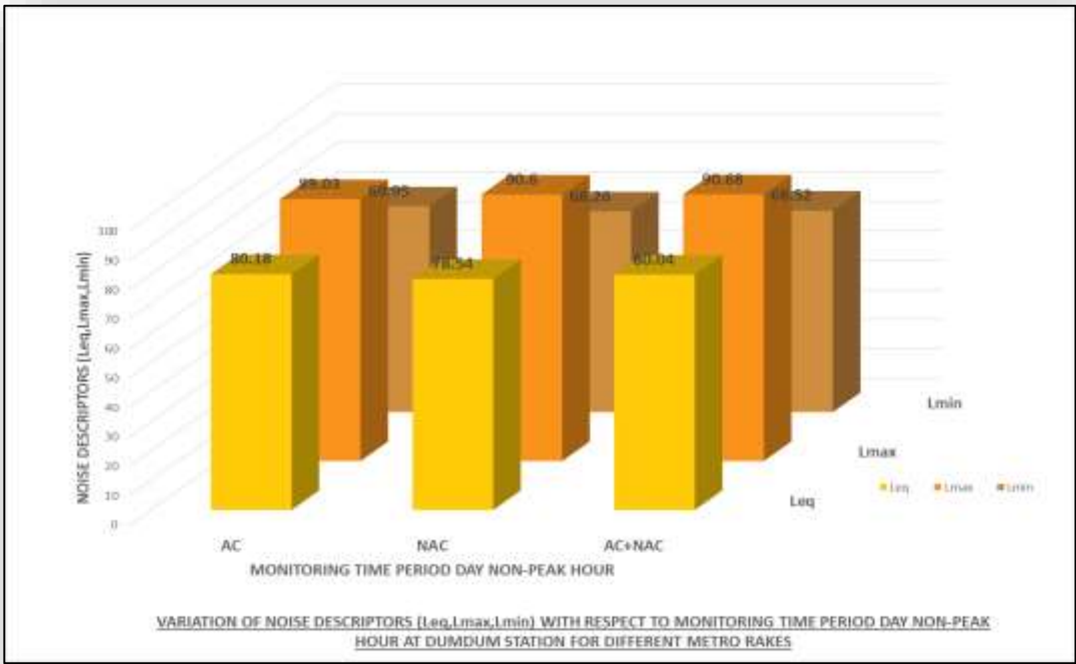


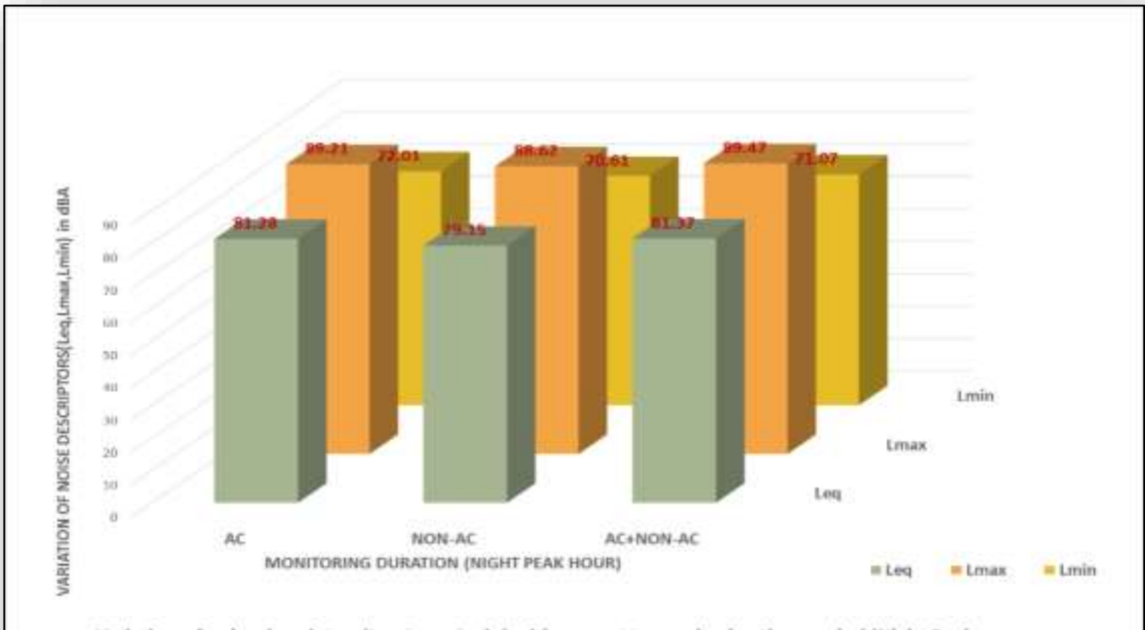
Fig-5.8: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time day non-peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Dumdum Metro Station

• From Fig-5.8, it is observed that equivalent noise level was **(80.04 dB(A))** in the case of noise due to combined movement of AC and Non-AC rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).

• In the case of AC rakes, equivalent noise level was measured as **(80.18 dB(A))** during the period of arrival, resting at platform and departure from platform.
• In the case of Non-AC rakes, equivalent noise level was measured as **(78.54 dB(A))** during the period of arrival, resting at platform and departure from platform.

- **Instantaneous noise data at night peak hour**

During night peak hour frequency of metro rakes was reasonably high, which was responsible for generation of higher noise level. However, in some cases longer standing time of metro rakes at platform was responsible for enhancement of average noise of platform.



Variation of noise descriptors(Leq,Lmax,Lmin) with respect to monitoring time period (Night Peak Hour) for different types of rakes at Dumdum Metro Station

Fig-5.9: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time night peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Dumdum Metro Station

• From Fig-5.9, it is observed that equivalent noise level was **(81.37 dB(A))** in the case of noise due to simultaneous movement of AC and Non-AC rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).
• In the case of AC rakes, equivalent noise level **(81.28 dB(A))** was measured during the period of arrival, staying at platform and departure from platform.

• In the case of Non-AC rakes, equivalent noise level was measured as **(79.15 dB(A))** during the period of arrival, staying at platform and departure from platform.

➢ Instantaneous noise data at night non-peak hour

During night non-peak hour frequency of metro rakes was reasonably low. Due to this lower frequency of metro rail, noise generated was little bit less. However, in some cases, longer standing time of metro rakes at platform was responsible for enhancement of average noise of platform.

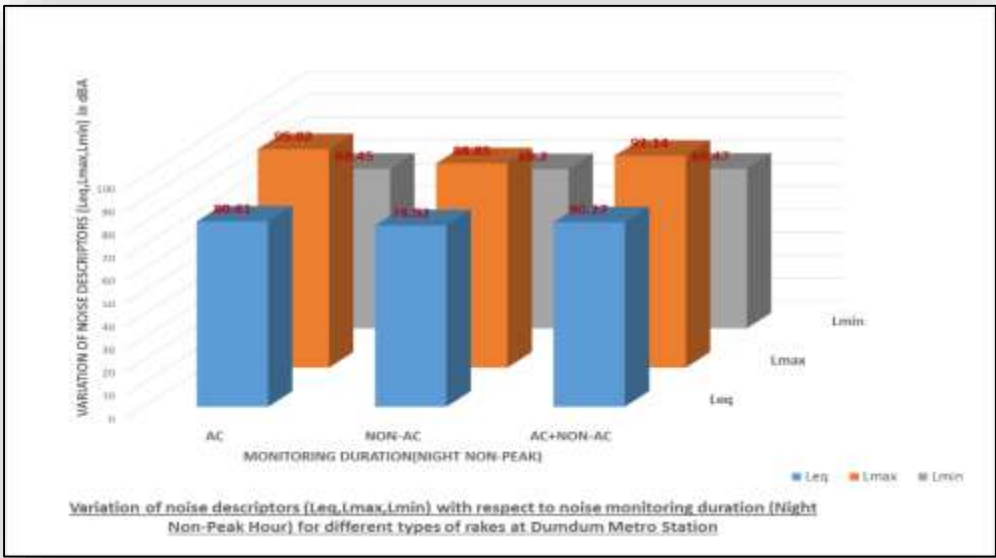


Fig-5.10: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time night non-peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Dumdum Metro Station

• From Fig-5.10, it is observed that equivalent noise level was (**80.27 dB(A))** in the case of noise due to simultaneous movement of AC and Non-AC rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).
• In the case of AC rakes, equivalent noise level **(80.61 dB(A))** was measured during the period of arrival, staying at platform and departure from platform.
• In the case of Non-AC rakes, equivalent noise level was measured as **(78.92 dB(A))** during the period of arrival, staying at platform and departure from platform.

Table-5.13: Descriptive statistical data of instantaneous noise from AC rakes at Dumdum Metro Railway Station

AC	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	81.25	82.92	80.18	1.20	1.48
L_{max}	91.15	95.02	89.03	2.79	3.06
L_{min}	71.07	72.86	69.45	1.63	2.29
L_1	88.06	89.50	87.19	1.02	1.16
L_{10}	84.07	85.82	82.90	1.25	1.49
L_{50}	79.79	81.64	78.64	1.44	1.80
L_{90}	76.41	78.06	75.14	1.37	1.80
L_{99}	73.14	74.70	71.97	1.26	1.73
NC	7.66	8.15	6.96	0.50	6.53
TNI	77.04	79.10	74.86	1.89	2.45

From above table it may be concluded that maximum and minimum value of L_{eq} were 82.92 dB(A) and 80.18 dB(A) respectively. Mean value of L_{eq} was 81.25 ± 1.20 dB(A).

This mean value of L_{eq} (81.25dB (A)) exceeds the CPCB prescribed value of L_{eq}, i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 77.04 ± 1.89 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the commuters and workers.

From correlation matrix of noise data generated from instantaneous noise monitoring at Dumdum Metro Railway Station for AC rakes (Ref., Table-9.7 of Annexure) it is revealed that,

i) Very high statistically significant positive correlation exists between L_{eq} and L_{10} (p=0.995). Linear proportional relationship exists between L_{eq} and L_1..It signifies that L_{eq} was influenced by L_{10}.
ii) Very high statistically significant positive correlation exists between L_{eq} and L_{50} (p=0.972). Linear proportional relationship exists between L_{eq} and L_{50}. It signifies that increase in equivalent noise (L_{eq}) is responsible for increase in median noise (L_{50}).
iii) Very high statistically significant positive correlation exists between L_{eq} and L_{90} (p=0.959). Linear proportional relationship exists between L_{eq} and L_{90}. It signifies that increase in background noise (L_{90}) is responsible for increase in equivalent noise (L_{eq}).

iv) Very high statistically significant positive correlation exists between L_{min} and L_{50} (p=0.974). Linear proportional relationship exists between L_{min} and L_{50}. It signifies that minimum noise (L_{min}) is influenced by median noise (L_{50}).

v) Very high statistically significant positive correlation exists between L_{min} and L_{90} (p=0.973). Linear proportional relationship exists between L_{min} and L_{90}. .It signifies that minimum noise (L_{min}) is influenced by background noise (L_{90}).

vi) Very high statistically significant positive correlation exists between L_{min} and L_{99} (p=0.990). Linear proportional relationship exists between L_{min} and L_{99}. It signifies that increase in minimum noise (L_{min}) is influenced by very background noise (L_{99}).

vii) Very high statistically significant positive correlation exists between L_{50} and L_{90} (p=0.990). Linear proportional relationship exists between L_{50} and L_{90}. It signifies that increase in background noise (L_{90}) is responsible for increase in median noise (L_{50}).

viii) Very high statistically significant positive correlation exists between L_{50} and L_{99} (p=0.994). Linear proportional relationship exists between L_{50} and L_{99}. It signifies that increase in median noise (L_{50}) is influenced by very background noise (L_{99}).

ix) Very high statistically significant positive correlation exists between L_{90} and L_{99} (p=0.982). Linear proportional relationship exists between $L_{90}$and L_{99}. It signifies that there is no such difference in background noise (L_{90}) and very background noise (L_{99}).

Table-5.14 Descriptive statistical data of instantaneous noise from Non-AC rakes at Dumdum Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	78.89	79.15	78.54	0.25	0.32
L_{max}	90.10	92.31	88.62	1.72	1.91
L_{min}	69.77	71.01	68.26	1.27	1.82
L_1	86.11	86.39	85.78	0.29	0.34
L_{10}	81.65	81.95	81.45	0.23	0.28
L_{50}	77.16	77.58	76.51	0.47	0.61
L_{90}	74.00	74.77	73.35	0.60	0.81
L_{99}	72.46	75.51	70.22	2.25	3.10
NC	7.66	8.18	6.73	0.67	8.70
TNI	74.62	76.49	71.69	2.11	2.83

From above table it may be concluded that maximum and minimum value of L_{eq} were 79.15 dB(A) and 78.54 dB(A) respectively. Mean value of L_{eq} was 78.89 ± 0.25 dB(A).

This mean value of L_{eq} **(78.89dB (A))** exceeds the CPCB prescribed value of L_{eq} , i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 74.62 ±2.11 dB(A) which is higher than the 74dB(A) (Ma et al.,2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the commuters and workers.

From, correlation matrix of noise data generated from instantaneous noise monitoring at Dumdum Metro Railway Station for Non-AC rakes (Annex Table-8) it can be concluded that,

i) Very high statistically significant positive correlation exists between L_{eq} and L_{50} (p=0.977). Linear proportional relationship exists between L_{eq} and L_{50} .It signifies that L_{eq} was influenced by L_{50}.
ii) Very high statistically significant negative correlation exists between L_{max} and L_1(p=-0.980). Inversely proportional relationship exists between L_{max} and L_1. It signifies that L_{max} is influenced by very peak noise L_1.
iii) Very high statistically significant positive correlation exists between NC and TNI (p=0.995). Linear proportional relationship exists between NC and TNI. It signifies that increase in NC is responsible for increase in TNI.

Table-5.15: Descriptive statistical data of instantaneous noise from combination of AC & Non-AC rakes at Dumdum Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	80.82	81.61	80.04	0.78	0.97
L_{max}	90.77	92.14	89.47	1.09	1.20
L_{min}	70.63	73.46	68.52	2.16	3.06
L_1	87.76	88.67	87.09	0.66	0.75
L_{10}	83.43	84.06	82.88	0.50	0.60
L_{50}	79.35	80.54	78.02	1.35	1.70
L_{90}	75.73	77.60	73.57	1.97	2.60
L_{99}	72.61	75.15	70.90	1.92	2.64
NC	7.70	9.65	5.94	1.63	21.16
TNI	76.52	82.17	71.36	4.60	6.02

From above table it may be concluded that maximum and minimum value of L_{eq} were 81.61 dB(A) and 80.04 dB(A) respectively. Mean value of L_{eq} was 80.82 ± 0.78 dB(A).

This mean value of L_{eq} **(80.82dB (A))** exceeds the CPCB prescribed value of L_{eq} , i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 76.52 ±4.60 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the commuters and workers.

From correlation matrix of noise data generated from instantaneous noise monitoring at Dumdum Metro Railway Station for combination of AC and Non-AC rakes (Annex Table-9) it can be concluded that,

i) Very high statistically significant positive correlation exists between L_{eq} and L_{50} (p=0.965). Linear proportional relationship exists between L_{eq} and L_{50} .It signifies that L_{eq} was influenced by L_{50}.
ii) Very high statistically significant positive correlation exists between L_{max} and L_1(p=0.983). Linear proportional relationship exists between L_{max} and L_1. It signifies that L_{max} is influenced by very peak noise L_1.
iii) Very high statistically significant positive correlation exists between L_{min} and L_{10}(p=0.995). Linear proportional relationship exists between L_{min} and L_{10}. It signifies that minimum noise (L_{min}) is influenced by peak noise (L_{10}).
iv) Very high statistically significant positive correlation exists between L_{min} and L_{99}(p=0.997). Linear proportional relationship exists between L_{min} and L_{99}. .It signifies that minimum noise (L_{min}) is influenced by very background noise (L_{99}).
v) Very high statistically significant positive correlation exists between L_{10} and L_{99}(p=0.984). Linear proportional relationship exists between L_{10} and L_{99}. It signifies that increase in very background noise (L_{99}) is responsible for increase in peak noise (L_{10}).
vi) Very high statistically significant positive correlation exists between L_{50} and L_{90} (p=0.992). Linear proportional relationship exists between L_{50} and L_{90}. It signifies that increase in background noise (L_{90}) is responsible for increase in median noise (L_{50}).
vii) Very high statistically significant negative correlation exists between L_{90} and NC (p=-0.979). Inversely proportional relationship exists between L_{90} and NC.
viii) Very high statistically significant negative correlation exists between L_{90} and TNI (p=-0.957). Inversely proportional relationship exists between L_{90} and TNI.

ix) Very high statistically significant positive correlation exists between NC and TNI (p=0.996). Linear proportional relationship exists between NC and TNI. It signifies that increase in NC is responsible for increase in TNI.

5.2.3.2 Instantaneous noise data of Netaji Metro Railway Station

Netaji Metro Railway station is one of the moderately crowded over-ground metro stations. This station is extremely influenced by high noise level of metro rakes and outside vehicular noise.

- **Instantaneous noise data at day peak hour**

During day peak hour, frequency of metro rake is too high, almost at 5.0mins interval. The present phase of study focused on individual noise generated by AC and Non-AC rakes and the noise generated from simultaneous movement of AC and Non-AC rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).

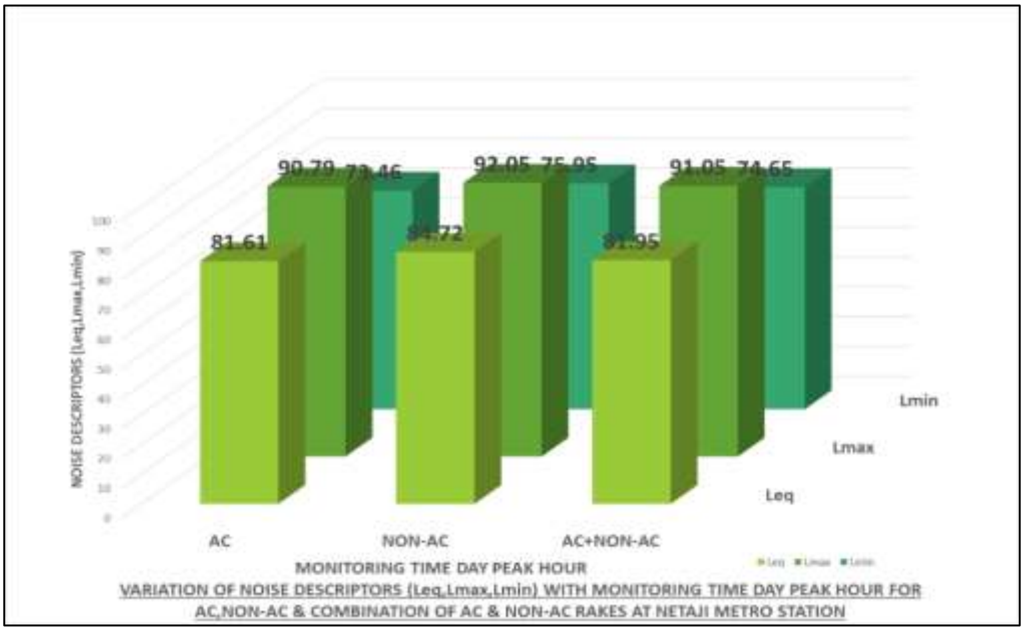


Fig-5.11: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time day peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Netaji Metro Station

• From Fig-5.11, it is observed that equivalent noise level was **(81.95 dB(A))** in the case of noise due to simultaneous movement of **AC and Non-AC** rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).

• In the case of **AC** rakes, equivalent noise level **(81.61 dB(A))** was measured during the period of arrival, staying at platform and departure from platform.
- In the case of **Non-AC** rakes, equivalent noise level was measured as **(84.72 dB(A))** during the period of arrival, staying at platform and departure from platform.

- **Instantaneous noise data at day non-peak hour**

During day non-peak hour, frequency of metro rakes was less. Consequently, noise generated was little bit less. However, in some cases longer standing time of metro rakes at platform was responsible for enhancement of average noise of platform.

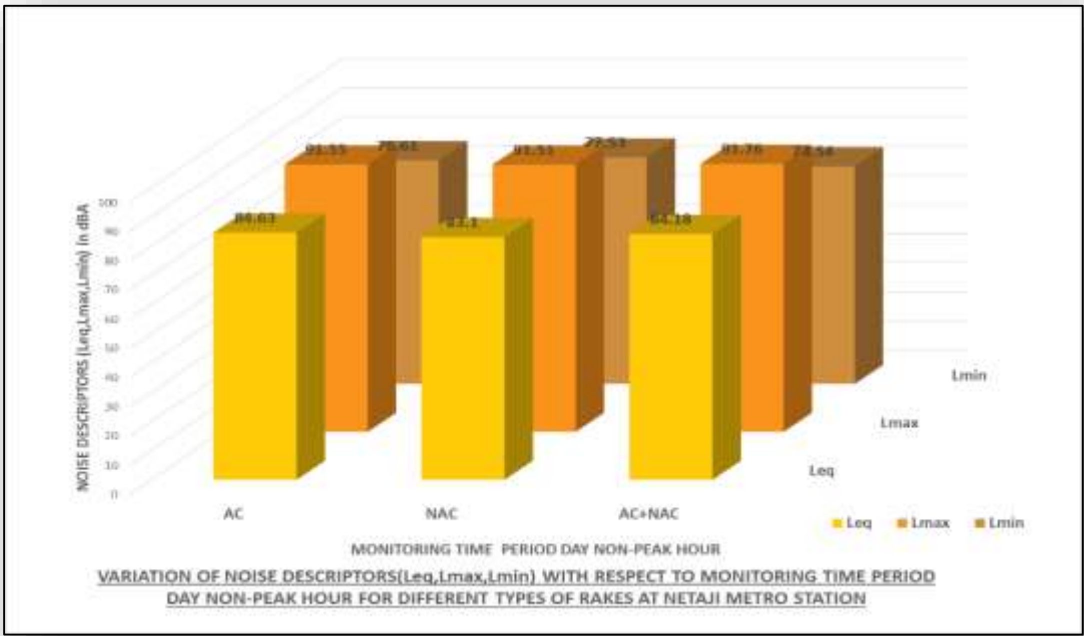


Fig:5.12 Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time day non-peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Netaji Metro Station

• From Fig-5.12, it is observed that equivalent noise level was **(84.18 dB(A))** in the case of noise due to **simultaneous movement of AC and Non-AC** rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).
• In the case of **AC** rakes, equivalent noise level **(84.63 dB(A))** was measured during the period of arrival, staying at platform and departure from platform.
• In the case of **Non-AC** rakes, equivalent noise level was measured as **(83.1 dB(A))** during the period of arrival, idling at platform and departure from platform.

➢ Instantaneous noise data at night peak hour

During night peak hours, frequency of train and number of commuters availing the metro route were relatively high. Hence, average noise level of the station was very high at that moment.

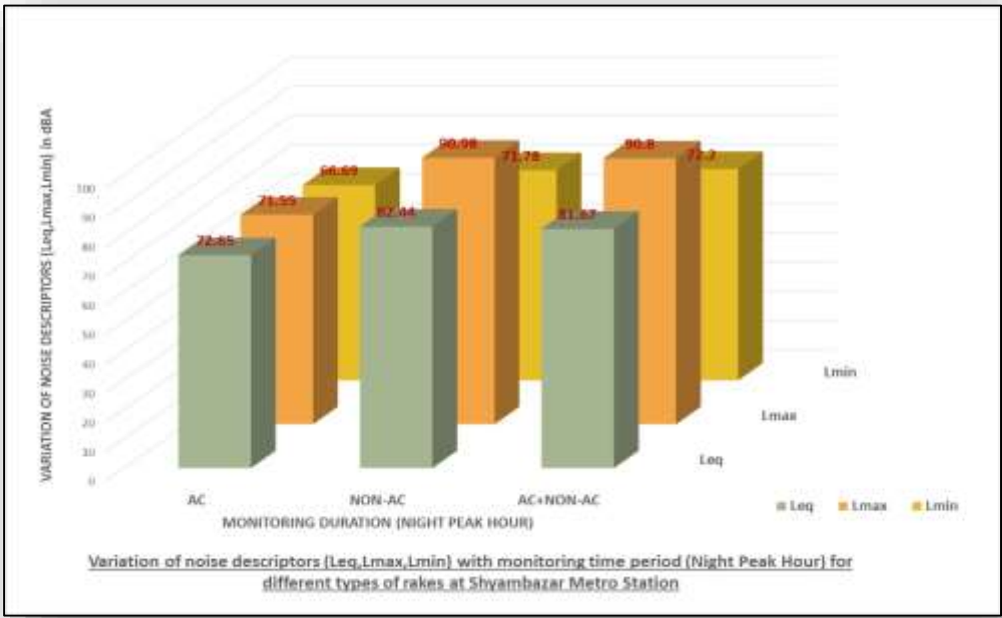


Fig-5.13: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time night peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Netaji Metro Station

• From Fig-5.13, it is observed that equivalent noise level was **(81.67 dB(A))** in the case of noise due to **simultaneous movement of AC and Non-AC** rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).
• In the case of **AC** rakes, equivalent noise level **(72.65 dB(A))** was measured during the period of arrival, staying at platform and departure from platform.
• In the case of **Non-AC** rakes, equivalent noise level was measured as **(82.44 dB(A))** during the period of arrival, staying at platform and departure from platform.

➢ Instantaneous noise data at night peak hour

During night non-peak hour frequency of metro rakes and number of commuters were relatively less. Hence, average noise level of the station was relatively low than peak time.

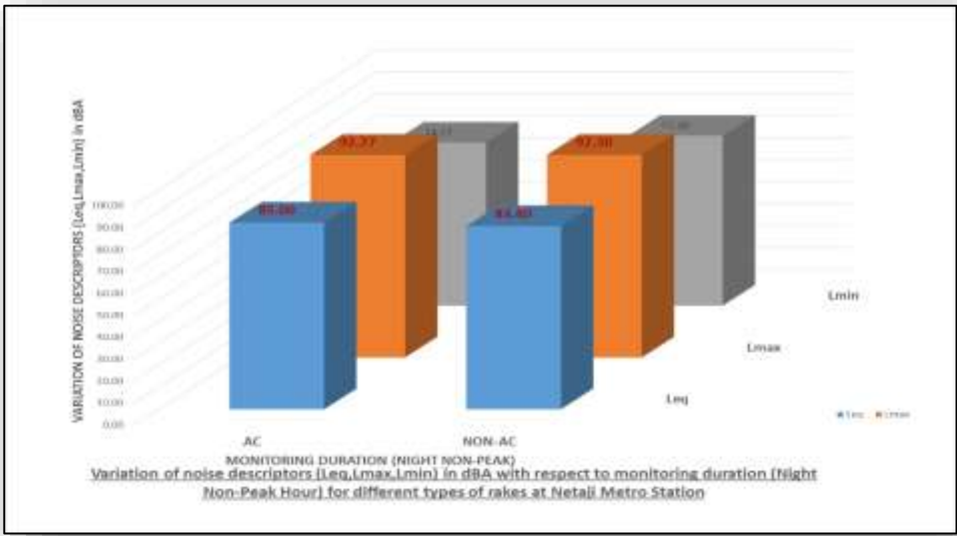


Fig-5.14: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time night non-peak hour for AC and Non-AC rakes at Netaji Metro Station

- From, Fig-5.14, it is observed that in the case of **AC** rakes, equivalent noise level **(85 dB(A))** was measured during the period of arrival, staying at platform and departure from platform.
- In the case of **Non-AC** rakes, equivalent noise level was measured as **(83.40 dB(A))** during the period of arrival, staying at platform and departure from platform.

Table-5.16: Descriptive statistical data of instantaneous noise from AC rakes at Netaji Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	84.40	85.00	83.58	0.62	0.73
L_{max}	91.60	92.27	90.53	0.77	0.85
L_{min}	75.79	76.61	74.17	1.11	1.47
L_1	90.63	91.57	89.32	0.96	1.05
L_{10}	88.08	88.90	86.97	0.83	0.94
L_{50}	82.37	82.94	81.32	0.72	0.88
L_{90}	79.14	79.67	78.30	0.59	0.74
L_{99}	76.81	77.59	75.47	0.97	1.26
NC	8.94	10.15	7.65	1.04	11.64
TNI	84.91	88.90	79.92	3.83	4.52

From above table it may be discussed that maximum and minimum value of L_{eq} were 85.0 dB(A) and 83.58 dB(A) respectively. Mean value of L_{eq} was 84.40 ± 0.62 dB(A).

This mean value of L_{eq} (84.40dB (A)) exceeds the CPCB prescribed value of L_{eq} ,i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 84.91 ± 3.83 dB(A) which is higher than the 74.0 dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the commuters and workers.

From, correlation matrix (Annex Table-10) of noise data generated from instantaneous noise monitoring at Netaji Metro Railway Station for AC rakes it may have concluded that,

i) Very high statistically significant positive correlation exists between L_{eq} and L_{max} (p=0.995). Linear proportional relationship exists between L_{eq} and L_{max}. It signifies that L_{eq} was influenced by L_{max}.

ii) Very high statistically significant positive correlation exists between L_{eq} and L_1(p=0.992). Linear proportional relationship exists between L_{eq} and L_1. It signifies that L_{eq} is influenced by very peak noise L_1.

iii) Very high statistically significant positive correlation exists between L_{eq} and L_{10}(p=0.998). Linear proportional relationship exists between L_{eq} and L_{10}. It signifies that equivalent noise (L_{eq}) is influenced by peak noise (L_{10}).

iv) Very high statistically significant positive correlation exists between L_{max} and L_1(p=0.991). Linear proportional relationship exists between L_{max} and L_1. It signifies that maximum noise (L_{max}) is influenced by very peak noise (L_1).

v) Very high statistically significant positive correlation exists between L_{max} and L_{10}(p=0.994). Linear proportional relationship exists between L_{max} and L_{10}. It signifies that increase in maximum noise (L_{max}) is influenced by peak noise (L_{10}) .

vi) Very high statistically significant positive correlation exists between L_{min} and L_{99}(p=0.979). Linear proportional relationship exists between L_{min} and L_{99}. It signifies that increase in very background noise (L_{99}) is responsible for increase in minimum noise (L_{min}).

vii) Very high statistically significant positive correlation exists between L_1 and L_{10} (p=0.998). Linear proportional relationship exists between $L_1$and L_{10}.

viii) Very high statistically significant positive correlation exists between L_{99} and TNI (p=0.993). Linear proportional relationship exists between L_{99} and TNI.

Table-5.17: Descriptive statistical data of instantaneous noise from Non-AC rakes at Netaji Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	82.85	83.40	81.95	0.63	0.76
L_{max}	91.60	92.30	91.05	0.52	0.57
L_{min}	75.66	77.53	73.15	2.12	2.80
L_1	90.03	91.03	89.42	0.69	0.77
L_{10}	86.48	86.87	85.60	0.60	0.69
L_{50}	80.35	81.04	79.57	0.76	0.95
L_{90}	76.83	78.83	75.60	1.40	1.83
L_{99}	75.19	77.90	73.69	1.95	2.59
NC	9.65	11.27	7.77	1.47	15.25
TNI	85.41	90.68	79.91	4.63	5.43

From Table-5.17 it may be concluded that maximum and minimum value of L_{eq} were 83.40 dB(A) and 81.95 dB(A) respectively. Mean value of L_{eq} was 82.85 ± 0.63 dB(A).

This mean value of L_{eq} (82.85 (A)) exceeds the CPCB prescribed value of L_{eq}, i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 85.41 ± 4.63 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the commuters and workers.

From correlation matrix of noise data generated from instantaneous noise monitoring at Netaji Metro Railway Station for Non-AC rakes (Ref Table-9.11 of Annexure) it is revealed that,

i) Very high statistically significant positive correlation exists between L_{max} and L_1 (p=0.988). Linear proportional relationship exists between L_{max} and L_1.
ii) Very high statistically significant positive correlation exists between NC and TNI (p=0.993). Linear proportional relationship exists between NC and TNI. It signifies that increase in NC cause increase in TNI

5.2.3.3 Instantaneous noise data of Belgachia Metro Railway Station

Belgachia Metro Railway station is one of the moderately crowded underground metro stations. This station is extremely influenced by high noise level of metro rakes.

➢ Instantaneous noise data at day peak hour

At day peak hour frequency of metro rake is too high, almost 5mins interval. Present study was focused on individual noise generated by AC rakes and Non-AC and as well it was also taken into account of noise generated from combination of AC and Non-AC rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).

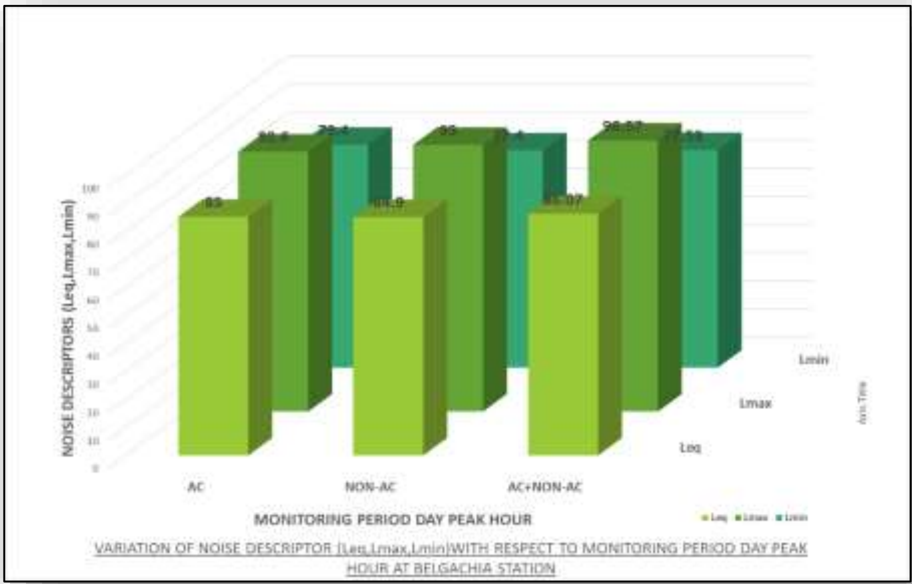


Fig-5.15 Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time day peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Belgachia Metro Station

• From, Fig-5.15, it is observed that equivalent noise level was (**86.07 dB(A))** in the case of noise due to **simultaneous movement of AC and Non-AC** rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).
• In the case of **AC** rakes, equivalent noise level **(85.0 dB(A))** was measured during the period of arrival, staying at platform and departure from platform.
• In the case of **Non-AC** rakes, equivalent noise level was measured as **(84.9 dB(A))** during the period of arrival, staying at platform and departure from the station.

➢ Instantaneous noise data at day non-peak hour

During day non-peak hour, frequency of metro rake is less, almost 15.0 mins interval. In this study noise monitoring was conducted for individual noise generated by AC and Non-AC rakes and from simultaneous movement of AC and

Non-AC rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).

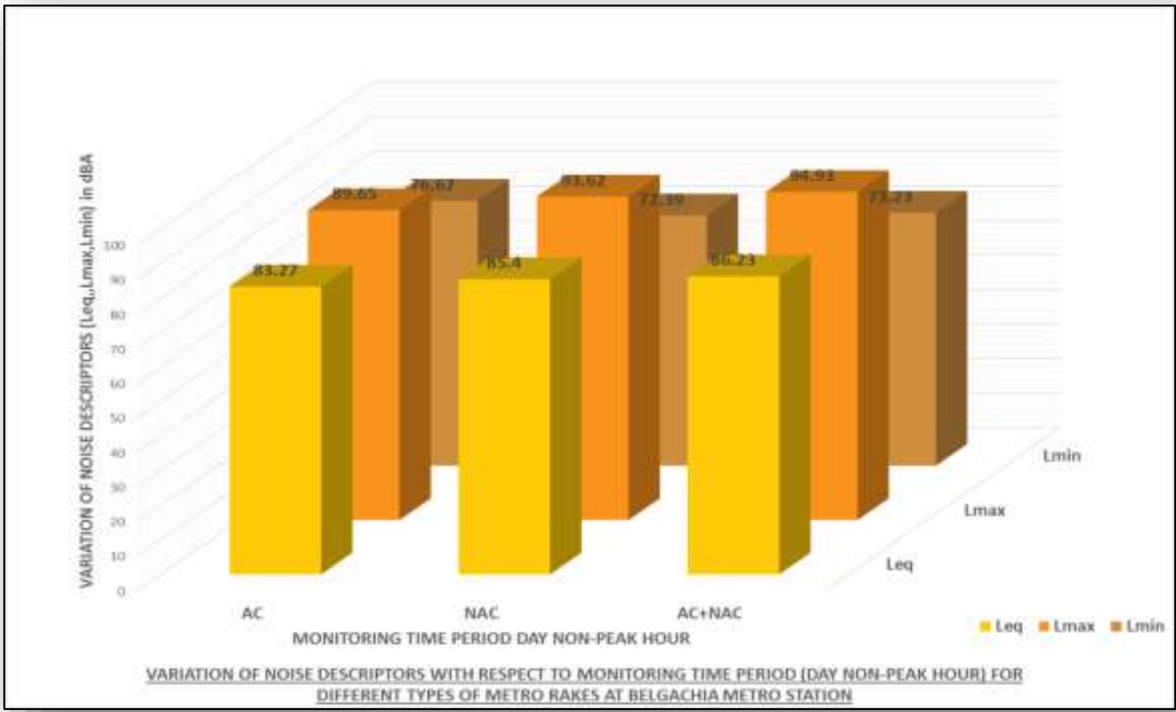


Fig-5.16: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time day non-peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Belgachia Metro Station

• From Fig-5.16, it is observed that equivalent noise level was **(86.23 dB(A))** in the case of noise due to **simultaneous movement of AC and Non-AC** rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).
• In the case of **AC** rakes, equivalent noise level **(83.27 dB(A))** was measured during the period of arrival, staying at platform and departure from platform.
• In the case of **Non-AC** rakes, equivalent noise level was measured as **(85.4 dB(A))** during the period of arrival, staying at platform and departure from platform.

➢ **Instantaneous noise data at night peak hour**

During night peak hour, it was observed that owing to frequent metro operation and larger number of passengers, A-weighted average noise level of platform was enhanced reasonably. Noise monitoring was conducted for AC, Non-AC and combination of AC and Non-AC individually.

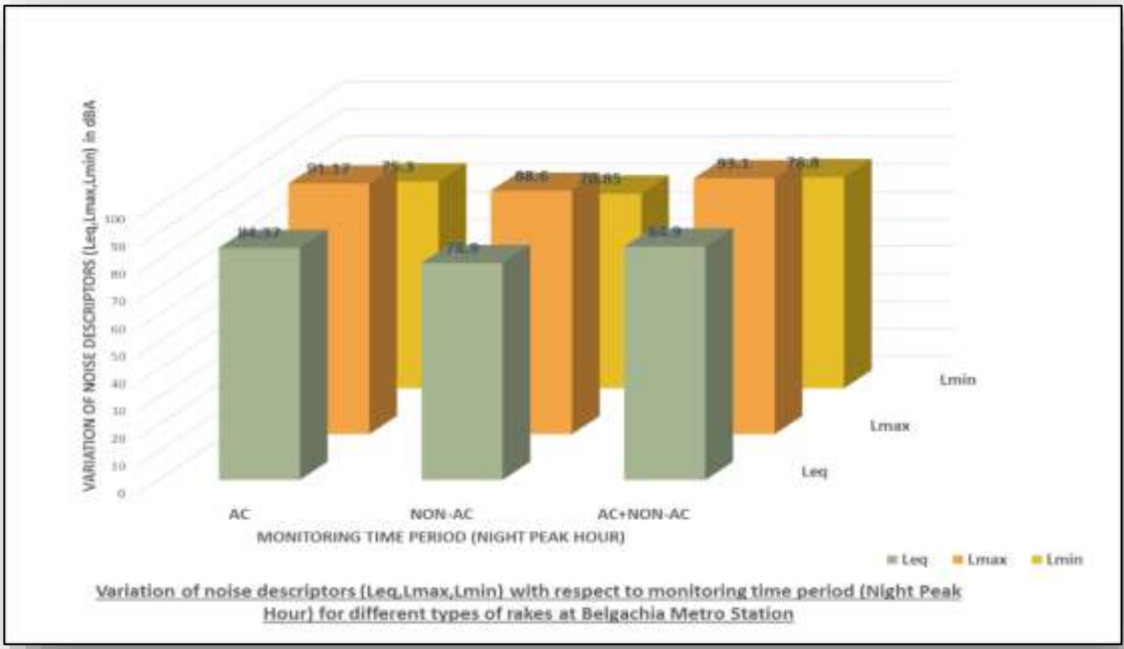


Fig-5.17: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time night peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Belgachia Metro Station

• From Fig: 5.17, it is observed that equivalent noise level was **(84.9 dB(A))** in the case of noise due to **simultaneous movement of AC and Non-AC** rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).
• In the case of **AC** rakes, equivalent noise level was measured as **(84.37 dB(A))** during the period of arrival, staying at platform and departure from platform
• In the case of **Non-AC** rakes, equivalent noise level **(78.9 dB(A))** was measured during the period of arrival, staying at platform and departure from platform.

➢ **Instantaneous noise data at night non-peak hour**

During night non-peak hour, frequency of rakes and passenger gathering were considerably less than peak hour. Therefore, average noise of platform was relatively less.

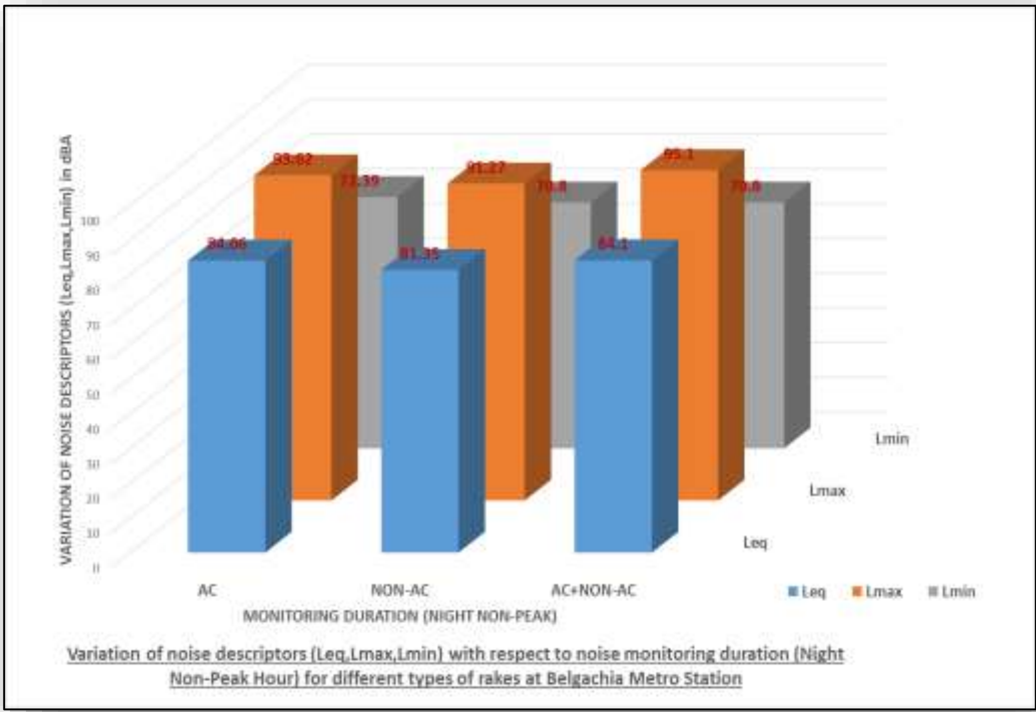


Fig-5.18: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time night non-peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Belgachia Metro Station.

- From Fig-5.18, it is observed that equivalent noise level was (**84.1 dB(A))** in the case of noise due to **simultaneous movement of AC and Non-AC** rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).
- In the case of **AC** rakes, equivalent noise level was measured as **(84.06 dB(A))** during the period of arrival, staying at platform and departure from platform.
- In the case of **Non-AC** rakes, equivalent noise level was measured as **(81.35 dB(A))** during the period of arrival, staying at platform and departure from platform.

Table-5.18: Descriptive statistical data of instantaneous noise from AC rakes at Belgachia Metro Railway Station

	MEAN	MIN	MAX	SD	%CV
L_{eq}	84.18	83.27	85.00	0.72	0.85
L_{max}	91.76	89.65	93.62	1.73	1.88
L_{min}	75.94	72.39	79.40	2.92	3.84
L_1	90.77	88.93	92.62	1.56	1.72
L_{10}	87.77	86.46	88.93	1.03	1.17
L_{50}	81.65	80.50	82.63	0.91	1.11
L_{90}	78.62	75.66	81.30	2.33	2.96
L_{99}	76.21	73.22	79.93	3.17	4.16
NC	9.15	7.32	11.95	2.14	23.44
TNI	85.22	78.42	93.46	6.57	7.71

From Table-5.18, it may be concluded that maximum and minimum value of L_{eq} were 83.27 dB(A) and 85 dB(A) respectively. Mean value of L_{eq} was 84.18±0.72 dB(A).

This mean value of L_{eq} (84.18 dB(A)) exceeds the CPCB standard of L_{eq} , i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 85.22 ± 6.57 dB(A) which is higher than the 74.0 dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the commuters and workers.

From correlation matrix of noise data generated from instantaneous noise monitoring at Belgachia Metro Railway Station for AC rakes (Annex Table-12) it is revealed that,

i) Very high statistically significant positive correlation exists between L_{eq} and L_{10} (p=1). Linear proportional relationship exists between L_{eq} and L_{10}. It signifies that equivalent noise (L_{eq}) is influenced by peak noise (L_{10}) .
ii) Very high statistically significant positive correlation exists between L_{max} and L_1 (p=0.993). Linear proportional relationship exists between L_{max} and L_1. It signifies that increase in maximum noise (L_{max}) is influenced by very peak noise (L_1) .
iii) Very high statistically significant positive correlation exists between L_{min} and L_{90} (p=0.997). Linear proportional relationship exists between L_{min} and L_{90}. It signifies that increase in background noise (L_{90}) is responsible for increase in minimum noise (L_{min}).
iv) Very high statistically significant positive correlation exists between TNI and NC (p=0.988). Linear proportional relationship exists between TNI and NC.

Table-5.19: Descriptive statistical data of instantaneous noise from Non-AC rakes at Belgachia Metro Railway Station

NOISE DESCRIPTORS	MEAN	MIN	MAX	SD	%CV
L_{eq}	81.88	78.90	85.40	3.28	4.01
L_{max}	91.16	88.60	93.62	2.51	2.76
L_{min}	71.35	70.80	72.39	0.90	1.27
L_1	89.42	85.55	92.62	3.58	4.01
L_{10}	85.29	82.60	87.61	2.52	2.96
L_{50}	78.17	76.85	80.50	2.03	2.59
L_{90}	73.99	72.80	75.66	1.49	2.01
L_{99}	72.21	71.55	73.22	0.89	1.23
NC	11.29	9.80	12.13	1.30	11.48
TNI	89.17	82.00	93.46	6.25	7.01

From Table-5.19, it is concluded that maximum and minimum value of L_{eq} were 85.40(A) and 78.90 dB(A) respectively. Mean value of L_{eq} was 81.88 ± 3.28 dB(A). This mean value of L_{eq} (81.88 dB(A)) exceeds the CPCB prescribed value of L_{eq}, i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.
TNI has its mean value of 89.17 ± 6.25 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the commuters and workers.

From, correlation matrix of noise data generated from instantaneous noise monitoring at Belgachia Metro Railway Station for Non-AC rakes (Ref, Table-9.13 of Annexure) it may be concluded that,

i) Very high statistically significant positive correlation exists between L_{eq} and L_{max} (p=0.961). Linear proportional relationship exists between L_{eq} and L_{max}. It signifies that equivalent noise (L_{eq}) is influenced by maximum noise (L_{max}) .
ii) Very high statistically significant positive correlation exists between L_{eq} and L_1 (p=0.964). Linear proportional relationship exists between L_{eq} and L_1. It signifies that increase in equivalent noise (L_{eq}) is influenced by very peak noise (L_1).
iii) Very high statistically significant positive correlation exists between L_{eq} and L_{10} (p=0.972). Linear proportional relationship exists between L_{eq} and L_{10}. It signifies that increase in equivalent noise (L_{eq}) is influenced by peak noise (L_{10}).
iv) Very high statistically significant positive correlation exists between L_{max} and L_1 (p=0.963). Linear proportional relationship exists between L_{max} and

L_1. It signifies that increase in maximum noise (L_{max}) is influenced by very peak noise (L_1).

v) Very high statistically significant positive correlation exists between L_{max} and L_{10} (p=0.983). Linear proportional relationship exists between L_{max} and L_{10}. It signifies that increase in maximum noise (L_{max}) is influenced by peak noise (L_{10})

vi) Very high statistically significant positive correlation exists between L_{min} and L_{90} (p=0.974). Linear proportional relationship exists between L_{min} and L_{90}. It signifies that increase in minimum noise (L_{min}) is influenced by background noise (L_{90})

vii) Very high statistically significant positive correlation exists between L_{min} and L_{99} (p=0.999). Linear proportional relationship exists between L_{min} and L_{99}. It signifies that increase in minimum noise (L_{min}) is influenced by very background noise (L_{99})

viii) Very high statistically significant positive correlation exists between L_1 and L_{10} (p=0.996). Linear proportional relationship exists between L_1 and L_{10}. It signifies that increase in very peak noise (L_1) is influenced by peak noise (L_{10}).

ix) Very high statistically significant positive correlation exists between L_{50} and L_{90} (p=0.975). Linear proportional relationship exists between L_{50} and L_{90}. It signifies that increase in median noise (L_{50}) is influenced by background noise (L_{90}).

x) Very high statistically significant positive correlation exists between L_{90} and L_{99} (p=0.978). Linear proportional relationship exists between L_{90} and L_{99}. It signifies that there is no such difference in background noise (L_{90}) and very background noise (L_{99}).

Table-5.20: Descriptive statistical data of instantaneous noise from combination of AC and Non-AC rakes at Belgachia Metro Railway Station

NOISE DESCRIPTORS	MEAN	MIN	MAX	SD	%CV
L_{eq}	85.33	84.10	86.23	1.01	1.18
L_{max}	94.93	93.10	96.57	1.42	1.50
L_{min}	74.59	70.80	77.53	3.15	4.22
L_1	93.20	92.00	93.90	0.88	0.95
L_{10}	88.92	87.40	89.80	1.05	1.18
L_{50}	83.14	80.40	84.43	1.85	2.22
L_{90}	78.11	73.80	80.70	3.03	3.89
L_{99}	75.61	71.60	78.13	3.01	3.98
NC	10.81	6.70	15.30	3.59	33.21
TNI	91.35	77.50	105.00	11.47	12.55

From Table-5.20 it is concluded that maximum and minimum value of L_{eq} were 86.23 dB(A) and 84.10 dB(A) respectively. Mean value of L_{eq} was 85.33 ± 1.01 dB(A).

This mean value of L_{eq} (85.33 dB(A)) exceeds the CPCB prescribed value of L_{eq}, i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 91.35 ± 11.47 dB(A) which is higher than the 74.0 dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the commuters and workers.

From correlation matrix of noise data generated from instantaneous noise monitoring at Belgachia Metro Railway Station for combination of AC and Non-AC rakes (Annex Table-14) it can be concluded that,

i) Very high statistically significant positive correlation exists between L_{min} and L_{99} (p=0.987). Linear proportional relationship exists between L_{min} and L_{99}. It signifies that minimum noise (L_{min}) is influenced by very background noise (L_{99}).
ii) Very high statistically significant positive correlation exists between L_{50} and L_{90} (p=0.957). Linear proportional relationship exists between L_{50} and L_{90}. It signifies that increase in median noise (L_{50}) is influenced by background noise (L_{90}).
iii) Very high statistically significant positive correlation exists between L_{90} and L_{99} (p=0.964). Linear proportional relationship exists between L_{90} and L_{99}. It signifies that there is no difference between background noise (L_{90}) and very background noise (L_{99}).
iv) Very high statistically significant negative correlation exists between L_{90} and NC (p=-0.963). Inversely proportional relationship exists between L_{90} and NC. It signifies that increase in background noise (L_{90}) is responsible for decrease in NC.
v) Very high statistically significant positive correlation exists between NC and TNI (p=0.997). Linear proportional relationship exists between NC and TNI. It signifies that increase in NC is responsible for increase in TNI.

5.2.3.4 Instantaneous noise data of Shyambazar Metro Railway Station

Shyambazar Metro Railway station is one of the overcrowded underground metro stations which is situated at the heart of North Kolkata. This station is extremely exposed to high level of noise of metro rakes and conversation of passenger's (during peak hour).

- **Instantaneous noise data at day peak hour**

During day peak hour, frequency of metro rake is reasonably high, almost at 5.0 mins interval. The present phase of study was focused on individual noise generated by AC rakes and Non-AC and the noise generated from simultaneous movement of AC and Non-AC rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake).

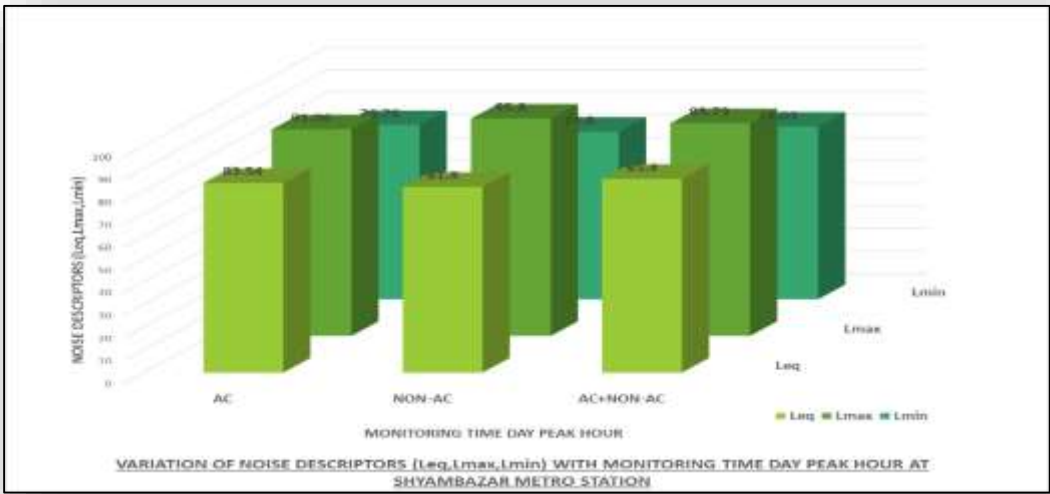


Fig-5.19: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time day peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Shyambazar Metro Station

- Above figure (Fig-5.19) shows that A-weighted equivalent noise level for combination of AC and Non-AC rakes was **85.40 dB(A).** Combination of both AC and Non-AC rakes produced high level of instantaneous noise, which resulted in an increase in A-weighted average platform noise.
- In the case of AC rakes, L_{eq} was measured as **83.54 dB(A)** during the period of arrival, staying at platform and departure from platform.
- In the case of **Non-AC** rakes, equivalent noise level was measured as **(81.9 dB(A))** during the period of arrival, staying at platform and departure from platform.

- **Instantaneous noise data at day non-peak hour**

During day non-peak hour, frequency of metro rake is less, almost at 15.0mins interval. In this phase of study, noise monitoring was conducted for individual noise generated by AC and Non-AC rakes. In this case, less gathering of passenger was observed and consequently average A-weighted equivalent noise level of platform was observed to be relatively less.

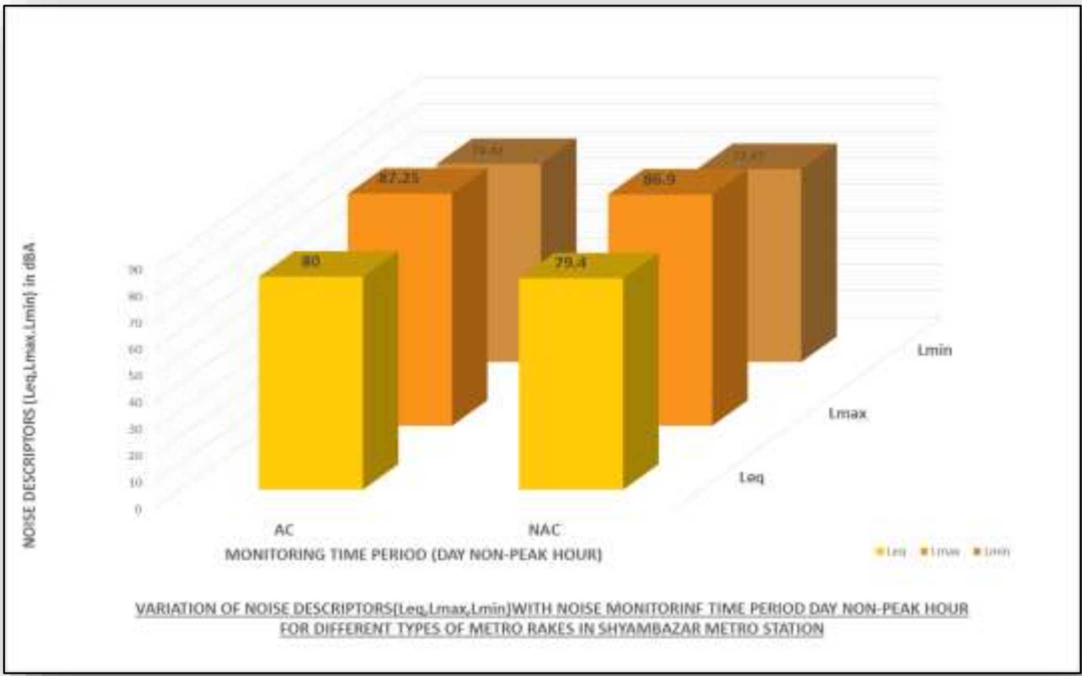


Fig-5.20: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time day non-peak hour for AC and Non-AC rakes at Shyambazar Metro Station

- In Fig-5.20, A-weighted equivalent noise for AC rakes was measured as **80.0 dB(A)** during arrival, staying at platform and departure moment of rakes from platform. During arrival and departure,
- In the case of **Non-AC** rakes, equivalent noise level was measured as **(81.9 dB(A))** during the period of arrival, staying at platform and departure from platform.

➢ **Instantaneous noise data at night peak hour**

During night peak hour, frequency of metro was considerably high. Larger public gathering was observed during that period at platform and consequently average A-weighted platform noise was increased.

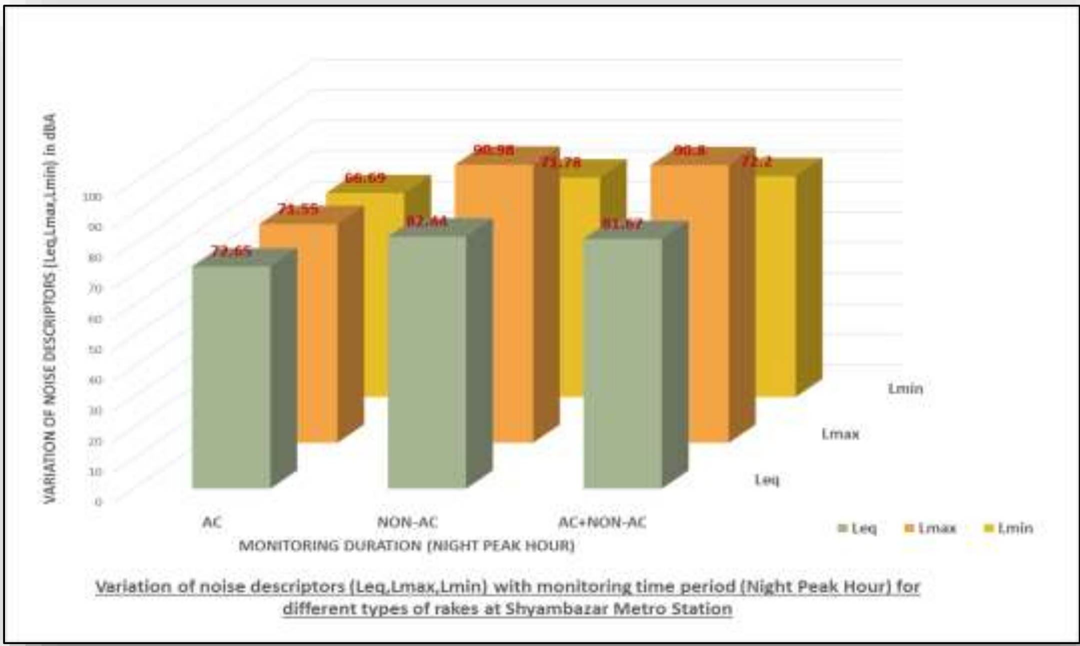
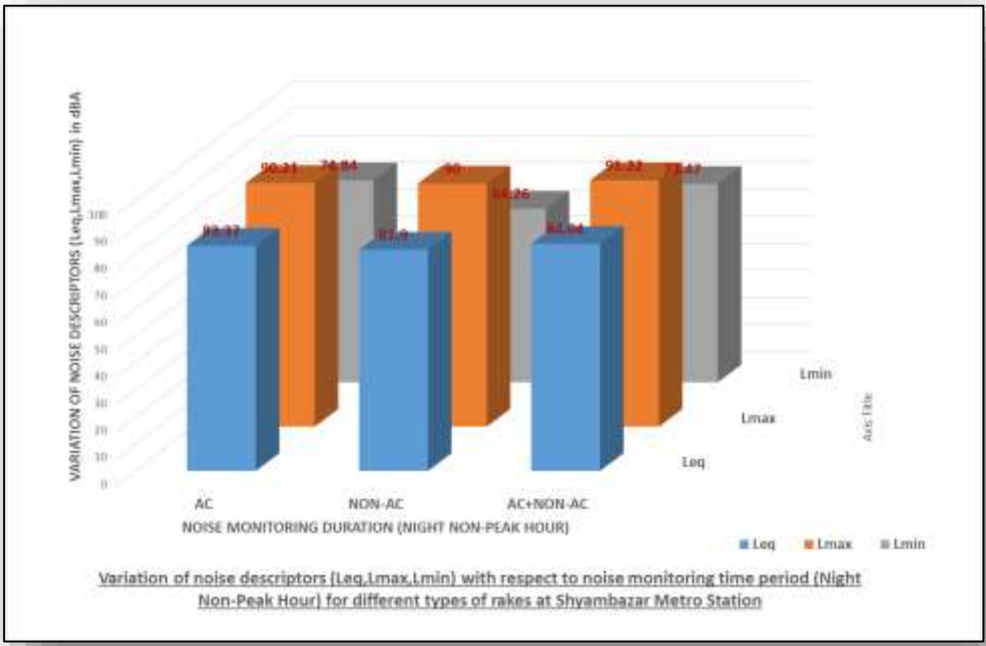


Fig-5.21: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time night peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Shyambazar Metro Station

- Above figure shows that A-weighted equivalent noise level for simultaneous movement of AC and Non-AC rakes was **81.67 dB(A).** Combination of both AC and Non-AC rakes produced high level of instantaneous noise and consequently A-weighted average platform noise increased.
- In the case of AC rakes L_{eq} was measured as **72.65 dB(A)** was during the period of arrival, staying at platform and departure from platform.
- In the case of **Non-AC** rakes, equivalent noise level was measured as **82.44 dB(A)** during the period of arrival, idling at platform and departure from platform.

➢ **Instantaneous noise data at night non-peak hour**

During night non-peak hour frequency of metro rake is relatively less, almost 15.0 minutes interval. In this study, noise monitoring was conducted for individual noise generated by AC, Non-AC and combination of AC and Non-AC rakes (e.g. at one platform AC rake and simultaneously at another Non-AC rake). In this case less gathering of passenger was observed and consequently increase in average A-weighted equivalent noise level of platform was not so high.



Variation of noise descriptors (Leq,Lmax,Lmin) with respect to noise monitoring time period (Night Non-Peak Hour) for different types of rakes at Shyambazar Metro Station

Fig-5.22: Variation of noise descriptors (L_{eq}, L_{max}, L_{min}) in dB(A) with instantaneous monitoring time night non-peak hour for AC, Non-AC and combination of AC & Non-AC rakes at Shyambazar Metro Station

- Above figure reveals the fact that, A-weighted equivalent noise level for simultaneous movement of AC and Non-AC rakes was **84.04 dB(A).** Combination of both AC and Non-AC rakes produced high level of instantaneous noise. For that reason, A-weighted average platform noise was increased.
- In the case of AC rakes, L_{eq} was measured as **83.37 dB(A)** during the period of arrival, staying at platform and departure from platform.
- In the case of **Non-AC** rakes, equivalent noise level was measured as **81.90 dB(A)** during the period of arrival, staying at platform and departure from platform.

Table-5.21: Descriptive statistical data of instantaneous noise from AC rakes at Shyambazar Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	79.89	83.54	72.65	5.09	6.38
L_{max}	85.02	91.06	71.55	9.13	10.73
L_{min}	73.18	76.76	66.69	4.44	6.07
L_1	88.00	89.70	85.57	1.84	2.09
L_{10}	85.38	87.28	82.77	1.99	2.33
L_{50}	80.63	82.64	78.82	1.75	2.17
L_{90}	77.78	79.09	76.50	1.35	1.73
L_{99}	75.90	77.46	74.93	1.18	1.55
NC	7.60	8.50	6.27	0.99	13.09
TNI	78.18	82.78	71.58	4.72	6.04

From above table it may be concluded that maximum and minimum value of L_{eq} were 83.54 dB(A) and 72.65 dB(A) respectively. Mean value of L_{eq} was 79.89 ± 1.01 dB(A).

This mean value of L_{eq} (79.89 dB(A)) exceeds the CPCB prescribed value of L_{eq}, i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 78.18 ± 4.72 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the commuters and workers.

From correlation matrix of noise data generated from instantaneous noise monitoring at Shyambazar Metro Railway Station for AC rakes (Annex Table-15) it may be concluded that,

i) Very high statistically significant positive correlation exists between L_{eq} and L_{max} (p=0.989). Linear proportional relationship exists between L_{eq} and $L_{max.}$ It signifies that equivalent noise (L_{eq}) is influenced by maximum noise (L_{max}).
ii) Very high statistically significant positive correlation exists between L_{eq} and L_{min} (p=0.971). Linear proportional relationship exists between L_{eq} and $L_{min.}$ It signifies that increase in equivalent noise (L_{eq}) is influenced by minimum noise (L_{min}).
iii) Very high statistically significant positive correlation exists between L_{max} and L_{min} (p=0.990). Linear proportional relationship exists between L_{max} and $L_{min.}$ It signifies that maximum noise (L_{max}) is increasing with increase in minimum noise (L_{min}).
iv) Very high statistically significant positive correlation exists between L_1 and L_{10} (p=1). Linear proportional relationship exists betweenL_1 and $L_{10.}$ It

signifies that there is no such difference between very peak noise (L_1) and peak noise (L_{10}).

v) Very high statistically significant positive correlation exists between L_{50} and L_{90} (p=0.979). Linear proportional relationship exists between L_{50} and L_{90}. It signifies that increase in background noise (L_{90}) is responsible for increase in median noise (L_{50}).

vi) Very high statistically significant positive correlation exists between NC and TNI (p=0.967). Linear proportional relationship exists between NC and TNI. It signifies that increase in NC is responsible for increase in TNI.

Table-5.22: Descriptive statistical data of instantaneous noise from Non-AC rakes at Shyambazar Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
L_{eq}	81.41	82.44	79.40	1.36	1.68
L_{max}	90.92	95.80	86.90	3.69	4.06
L_{min}	70.58	73.80	64.26	4.29	6.08
L_1	87.75	89.64	85.80	1.69	1.93
L_{10}	85.28	86.89	83.00	1.71	2.01
L_{50}	79.52	80.44	77.63	1.28	1.61
L_{90}	75.76	76.30	74.63	0.76	1.00
L_{99}	73.36	74.20	72.76	0.61	0.84
NC	9.53	10.80	8.37	1.18	12.35
TNI	83.87	89.29	78.11	5.16	6.15

From above table it may be concluded that maximum and minimum value of L_{eq} were 82.44 dB(A) and 79.40 dB(A) respectively. Mean value of L_{eq} was 81.41 ± 1.36 dB(A).

This mean value of L_{eq} (81.41 dB(A)) exceed the CPCB prescribed value of L_{eq} ,i.e. 65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 83.87 ± 5.16 dB(A) which is higher than the 74dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise is verily annoying to the commuters and workers.

From correlation matrix of noise data generated from instantaneous noise monitoring at Shyambazar Metro Railway Station for Non-AC rakes (Annex Table-16) it is revealed that,

i) Very high statistically significant positive correlation exists between L_{eq} and L_{50} (p=0.964). Linear proportional relationship exists between L_{eq} and L_{50}. It signifies that equivalent noise (L_{eq}) is influenced by median noise (L_{50}) .

ii) Very high statistically significant positive correlation exists between L_{10} and L_{50} (p=0.952). Linear proportional relationship exists between L_{10} and L_{50}. It signifies that increase in peak noise (L_{10}) is influenced by median noise (L_{50}).

iii) Very high statistically significant positive correlation exists between L_{10} and TNI (p=0.967). Linear proportional relationship exists between L_{10} and TNI.

iv) Very high statistically significant positive correlation exists between L_{50} and L_{90} (p=0.954). Linear proportional relationship exists between L_{50} and L_{90}. It signifies that increase in background noise (L_{90}) is responsible for increase in median noise (L_{50}).

v) Very high statistically significant positive correlation exists between NC and TNI (p=0.967). Linear proportional relationship exists between NC and TNI. It signifies that increase in NC is responsible for increase in TNI.

5.2.4 Noise monitoring within rakes (AC and Non-AC) at different commercial hours of Kolkata Metro Railway

In this present study, to investigate the extent of noise annoyance of passengers while travelling by different types of metro rakes (AC and Non-AC), noise quality monitoring was conducted within that types of rakes (AC and Non-AC) under moving condition from Dumdum to Kavi Subhash at different commercial hours of Kolkata Metro Railway. Noise measurement was made at passenger's sitting level.

5.2.4.1 Noise monitoring within AC and Non-AC rakes

Noise quality monitoring was conduct within AC and Non-AC rakes from Dumdum to Kavi Subhash Metro Railway Station at passenger's sitting level.

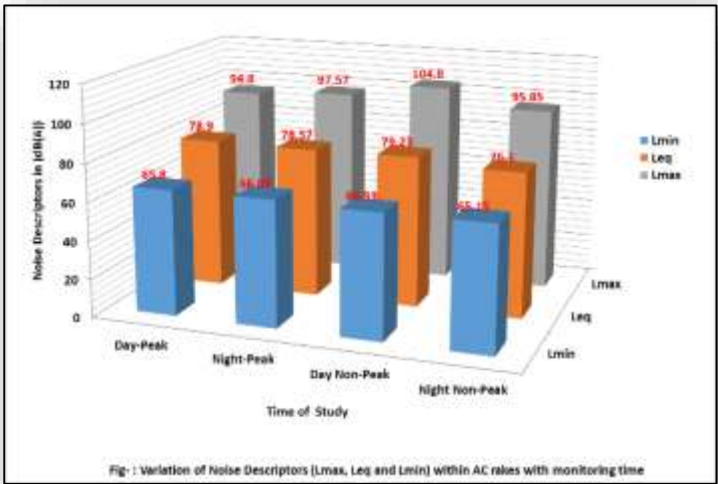


Fig-5.23: Variation of noise descriptors (L_{min}, L_{eq}, L_{max}) in dB(A) within AC rakes with continuous monitoring time at different commercial hour of Kolkata Metro Railway

From this above figure it may be discussed that A-weighted equivalent noise level at Day-Peak, Night-Peak, Day Non-Peak and Night Non-Peak were 65.8 dB(A),66.03 dB(A), 64.93 dB(A) and 65.15 dB(A) respectively.

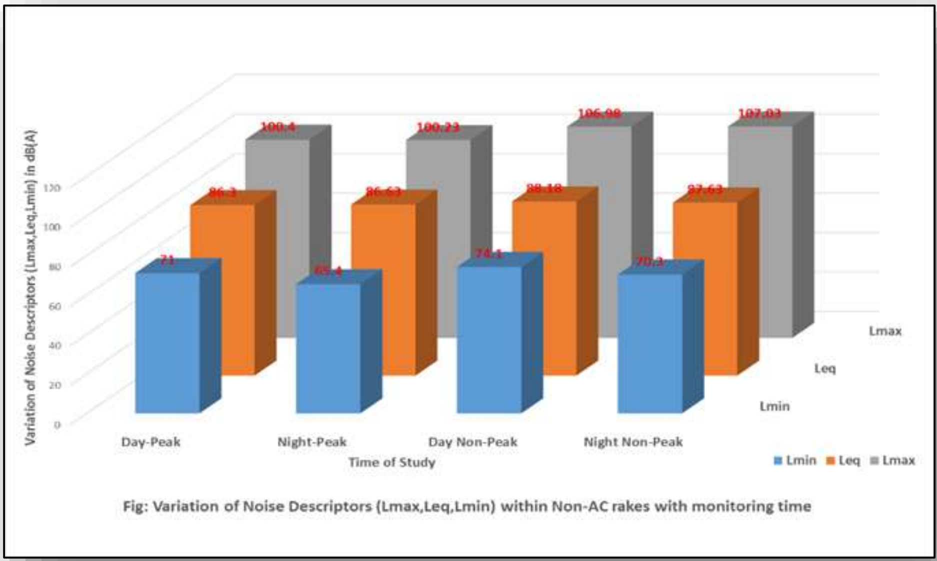


Fig: Variation of Noise Descriptors (Lmax,Leq,Lmin) within Non-AC rakes with monitoring time

Fig-5.24: Variation of noise descriptors (L_{min}, L_{eq}, L_{max}) in dB(A) within Non-AC rakes with continuous monitoring time at different commercial hour of Kolkata Metro Railway

From Fig: 5.24, it is observed that A-weighted equivalent noise was maximum in night peak hour following then day peak hour for extreme gathering of passengers for Non-AC rake.
In course of the present study, the following sources of noise generation within AC and Non-AC rakes have been identified:

i) Extreme rail-wheel interaction noise during movement through underground tunnel structure.
ii) Public address system to make passenger alert.
iii) Jerking of coach during movement of rake produces high level noise.
iv) Ventilation system noise.
v) Door operational noise
vi) At metro station stoppage, some platform noise also enters into rakes.
vii) During stopping operation, application of break produces frictional noise.
viii) At day and night peak hour gathered passenger conversation was also enhanced A-weighted equivalent noise level.
ix) Ringing alarm during operational moment.
x) Rattling noise from ceiling panels for ventilation and air conditioning for AC rakes.
xi) During movement through tunnel portion some reverberation noise was communicated inside the metro rakes through ventilation system.

xii) High speed sweeping of fan fitted on the ceiling of Non-AC rakes.

xiii) Due to lack of maintenance in some AC and Non-AC rakes, additional noise was generated.

Although rake body also act as a noise shield, but in this case these aforesaid noise was really make annoyance to the passenger.

Table-5.23: Descriptive statistical data of continuous noise within AC rakes during movement from Dumdum Metro Railway Station to Kavi Subhash Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
n	2.25	3.00	1.00	0.96	42.55
L_{eq}	78.20	79.23	76.10	1.43	1.82
L_{max}	98.26	104.80	94.80	4.51	4.59
L_{min}	65.48	66.03	64.93	0.52	0.80
L_1	85.33	86.80	82.80	1.83	2.14
L_{10}	80.78	81.33	79.30	0.99	1.23
L_{50}	76.28	77.90	74.55	1.37	1.80
L_{90}	72.72	75.20	69.45	2.48	3.41
L_{99}	69.96	73.10	66.95	2.63	3.76
NC	8.31	9.85	6.10	1.59	19.16
TNI	75.72	78.85	69.60	4.19	5.53

From above table it may be concluded that maximum and minimum value of L_{eq} were 79.23dB(A) and 76.10 dB(A) respectively. Mean value of L_{eq} was 78.20±1.43 dB(A).

This mean value of L_{eq} (79.20 dB(A)) exceed the CPCB prescribed value of L_{eq} ,65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 75.72 ± 4.19 dB(A) which is higher than the 74dB(A) (Ma et al.,2006), defined as threshold of over criterion, which might be attribute to the fact that this noise is verily annoying to the residents.

It is also observed that coefficient of variation of number of rakes (n) was 42.55%, which is higher than coefficient of variation of L_{eq} , 1.82%, that means noise level did not vary such extent with the variation of number of rakes.

From, correlation matrix of noise data generated from noise monitoring within AC rakes (Annex Table-20) it may be concluded that,

i) Very high statistically significant positive correlation exists between L_{eq} and L_{10} (p=0.970). Linear proportional relationship exists between L_{eq} and L_{10}. It signifies that equivalent noise (L_{eq}) is influenced by peak noise (L_{10}).

ii) Very high statistically significant positive correlation exists between L_{50} and L_{90} (p=0.958). Linear proportional relationship exists between L_{50} and L_{90}. It is concluded that median noise is influenced by background noise.

iii) Very high statistically significant positive correlation exists between L_{50} and L_{99} (p=0.957). Linear proportional relationship exists between L_{50} and L_{99}. It signifies that median noise is influenced by very background noise.

iv) Very high statistically significant negative correlation exists between L_{50} and NC (p=-0.951). Inversely proportional relationship exists between L_{50} and NC. It signifies that increase in median noise with decrease in NC.

v) Very high statistically significant positive correlation exists between L_{90} and L_{99} (p=0.977). Linear proportional relationship exists between L_{90} and L_{99} .. It signifies that there is no such difference in background and very background noise.

vi) Very high statistically significant negative correlation exists between L_{99} and NC (p=-0.951). Inversely proportional relationship exists between L_{99} and NC. It signifies that increase in very background noise with decrease in NC.

vii) Very high statistically significant positive correlation exists between NC and TNI (p=0.984). Linear proportional relationship exists between NC and TNI. It signifies that increase in noise climate (NC) is responsible for increase in traffic noise index (TNI).

Table-5.24: Descriptive statistical data of continuous noise within Non-AC rakes during movement from Dumdum Metro Railway Station to Kavi Subhash Metro Railway Station

	MEAN	MAX	MIN	STDEV	%CV
n	2.75	4.00	1.00	1.26	45.76
L_{eq}	87.19	88.18	86.30	0.87	1.00
L_{max}	103.66	107.03	100.23	3.86	3.73
L_{min}	70.20	74.10	65.40	3.60	5.13
L_1	94.81	95.65	93.70	0.86	0.90
L_{10}	91.12	92.10	90.20	0.80	0.87
L_{50}	84.04	84.88	82.87	0.88	1.05
L_{90}	75.80	78.25	73.23	2.08	2.75
L_{99}	72.84	75.90	69.20	2.79	3.84
NC	15.32	17.63	13.85	1.81	11.83
TNI	107.08	113.75	101.90	5.38	5.02

From above table (Ref Table:5.24) it is concluded that maximum and minimum value of L_{eq} were 88.18dB(A) and 86.30 dB(A) respectively. Mean value of L_{eq} was 87.19±0.87 dB(A).

This mean value of L_{eq} (87.19 dB(A)) exceed the CPCB prescribed value of L_{eq} ,65 dB(A) for day time and 55 dB(A) for night time for commercial area.

TNI has its mean value of 107.08 ±5.38 dB(A) which is higher than the 74dB(A) (Ma et al.,2006), defined as threshold of over criterion, which might be attribute to the fact that this noise is verily annoying to the residents.

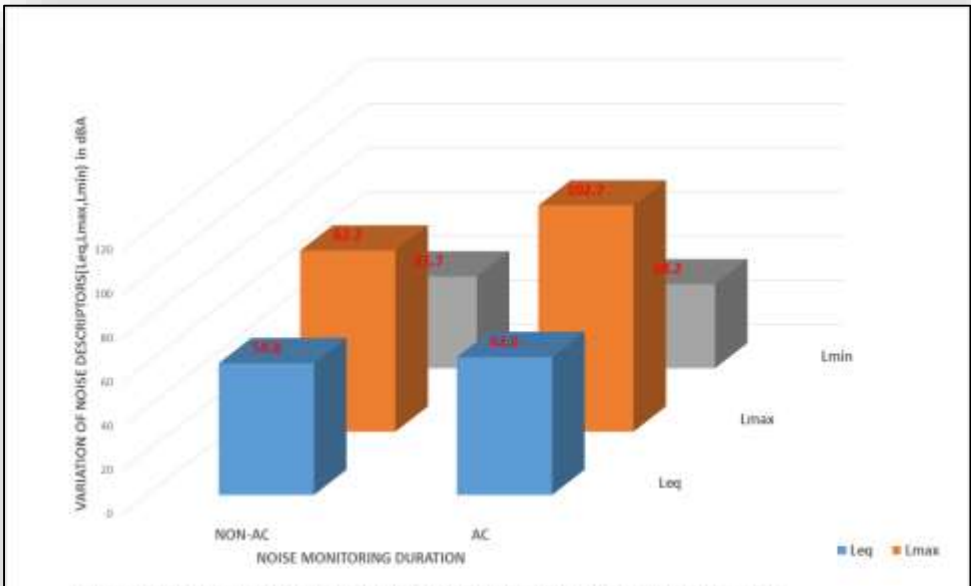
It is also observed that coefficient of variation of number of rakes (n) was 45.76%, which is higher than coefficient of variation of L_{eq} .1%, that means noise level did not vary such extent with the variation of number of rakes.

From, correlation matrix of noise data generated from noise monitoring within Non-AC rakes (Annex Table-21) it may be concluded:

i) Very high statistically significant positive correlation exists between L_{eq} and L_1 (p=0.957). Linear proportional relationship exists between L_{eq} and L_1. It signifies that equivalent noise (L_{eq}) is influenced by very peak noise (L_1) .
ii) Very high statistically significant positive correlation exists between L_{eq} and L_{10} (p=0.966). Linear proportional relationship exists between L_{eq} and L_{90}. It signifies that equivalent noise (L_{eq}) is influenced by peak noise (L_{10})
iii) Very high statistically significant positive correlation exists between L_{min} and L_{90} (p=0.989). Linear proportional relationship exists between L_{min} and L_{90}. It is concluded that minimum noise is influenced by background noise.
iv) Very high statistically significant positive correlation exists between L_{min} and L_{99} (p=0.996). Linear proportional relationship exists between L_{min} and L_{99}. It signifies that there is no such difference in very background noise (L_{99}) and minimum noise (L_{min}).
v) Very high statistically significant positive correlation exists between L_1 and L_{10} (p=0.969). Linear proportional relationship exists between L_1 and L_{10}. It signifies that there is no such difference in very peak noise (L_1) and peak noise (L_{10}).
vi) Very high statistically significant positive correlation exists between L_{90} and L_{99} (p=0.996). Linear proportional relationship exists between L_{90} and L_{99}. It signifies that there is no such difference in very background noise (L_{99}) and background noise (L_{90}).
vii) Very high statistically significant positive correlation exists between NC and TNI (p=0.989). Linear proportional relationship exists between NC and TNI. It signifies that increase in noise climate (NC) is responsible for increase in traffic noise index (TNI).

5.2.5 Noise monitoring within rakes (AC and Non-AC) at Kavi Subhash Car Shed of Kolkata Metro Railway

To investigate background noise with rakes (AC and Non-AC), present study conduct noise monitoring at each rake in fully dead condition means, rakes were at rest and all noise producing sources within rakes were in off condition.



Variation of noise descriptors (Leq,Lmax,Lmin) with respect to noise monitoring duration for different types of rakes at Kavi Subhash Carshed

Fig-5.25: Variation of noise descriptors (L_{min}, L_{eq}, L_{max}) in dB(A) within AC and Non-AC rakes with continuous monitoring time at Kavi Subhash Carshed of Kolkata Metro Railway

Above Fig:5.25, indicates that A-weighted background noise within AC rake was 62.6 dB(A) and within Non-AC rake was 59.8 dB(A).

In the case of AC rake, background noise was highly influenced by ongoing maintenance work at that carshed, bird's noise, worker's conversation etc.

In the case of Non-AC rake, background noise was also influenced by some extent of maintenance work, bird's noise and worker's conversation.

Chapter-6

Conclusion

Observed sources of noise levels

Present study reveals the fact that sources of these noise levels at different noise monitoring stations were as follows:

- ✓ At metro railway platforms, major sources of high level of noise were identified as rail-wheel interaction, door operation, public address system, ventilation system (for underground platform), auxiliary electrical equipment, fan fitted at platform (overground station platform), ongoing maintenance activities and conversation, outside vehicular noise (for overground Netaji station) and EMU railway noise (for overground Dumdum station only).
- ✓ Within rakes the noise sources are public address system, braking noise, jerking noise, door operation noise, fan noise (for Non-AC rakes only), ventilation system noise, compressor noise and conversation of passengers.
- ✓ Within the school, apart from movement of metro rakes major noise sources are students and worker activities and some outdoor noise.
- ✓ At the residential building, adjacent to Dumdum metro station, besides metro noise, EMU noise and noise due to different domestic activities acted as an additional contributor to the noise.

Results obtained

- ✓ In the case of monitoring at metro platforms it was observed that, for overground metro stations, day time and night time average background noise was **(1.9 - 9.7) dB(A)** and **(0.7 – 2.0) dB(A)** more than the respective WHO standard (Ref. Table-6.3).
- ✓ At underground metro station platforms, it was observed that, A-weighted day and night time background noise was within the prescribed limit (Ref Table-6.3)).
- ✓ In the case of school building adjacent to metro railway track, day time A-weighted average background noise was **3.2 dB(A)** higher than the recommended value (Ref. Table-6.1).
- ✓ In the case of residential building near Dumdum metro railway station night time back ground noise was **12.8 dB(A)** higher than prescribed standard (Ref Table-6.3)).
- ✓ In the case of average noise study at different monitoring points over 2.0 hours of continuous monitoring period, the A-weighted average noise for overground metro platforms was higher than the respective ambient noise standard prescribed by CPCB for commercial area by the extent of **(15.7 - 17.2) dB(A)** during **day peak hour, (16.4 - 17.2) dB(A)** during **day non-peak hour, (26 - 28.2) dB(A)** during

night peak hour and **(24 - 25.1) dB(A)** during **night non-peak hour** (Ref. Table-6.1).

- ✓ For underground metro station, A-weighted average noise level was higher than the prescribed CPCB standards by the extent of **(14.6 - 15.5) dB(A)** during day peak hour, **(14.2 - 14.3) dB(A)** during day non-peak hour and **(24.3 - 24.6) dB(A)** during night peak hour respectively.
- ✓ In the noise monitoring study at a school building (Near Netaji Metro station), average A-weighted equivalent sound level was **14.44 dB(A), 23.4 dB(A), 20.50 dB(A)** and **14.4 dB(A)** higher than prescribed CPCB noise standard during day peak, day non-peak, night peak and night non-peak hours.
- ✓ In residential building, average noise level was **7.0 dB(A)** and **8.1 dB(A)** higher than CPCB recommended noise standard at night peak and night non-peak hours respectively.
- ✓ Noise Quality study within Non-AC rakes indicates this fact that under moving condition, average equivalent noise level **(78.89 dB(A))** was within the recommended standard (Ref. Table-6.3). On the contrary, for AC-rakes under moving condition, the average equivalent noise level **(81.25 dB(A))** exceeded the recommended standard (Ref. Table-6.3). It may have been contributed by the air-conditioning system within the AC-rakes, which may not have been properly maintained.
- ✓ From descriptive statistical interpretation it can be concluded that mean value of traffic noise index (TNI) was maximum (101.58 dB(A)) in the case of Belgachia metro station for average noise measurement. In residential building it was 84.10 dB(A), for Non-AC rakes it was 107.08 dB(A) and for AC rakes it was 75.72 dB(A). In all cases these TNI values were exceeded 74 dB(A) (Ma et al., 2006), defined as threshold of over criterion, which might be attributed to the fact that this noise was reasonably annoying to the commuters and workers for metro station and metro rakes and it will impose a potential threat to all stakeholders, who are exposed to such a high level of noise.

The major conclusion which can be drawn from the outcome of the present study is that, in most of the cases measured equivalent sound level (L_{eq}) exceeds the ambient noise standard prescribed by CPCB (Table-6.1) and also the noise exposure limits for community/urban type noise influence area prescribed by World Health Organization (WHO) (Table-6.2).

Table-6.1: CPCB (Central Pollution Control Board) prescribed ambient air quality standard in respect of noise

Area Code	Category of Area / Zone	Limits in dB(A) Leq*	
		Day Time	Night Time
(A)	Industrial area	75	70
(B)	Commercial area	65	55
(C)	Residential area	55	45
(D)	Silence Zone	50	40

(Source: The noise pollution (regulation and control) rules, 2000)
(Here, **Day time**: **6:00 AM to 10:00 PM** & **Night time**: **10:00 PM to 6:00 AM** were considered.)

Table-6.2: WHO recommended noise exposure limits and physical problems associated with these limits (if exceed these limits) for different types of noise influence area

Environment	*Recommended maximum L_{eq} level (dB(A))*	*Effects*
Industrial/occupational	75	Predictable risk of hearing impairment at higher levels
Community/urban		
daytime	55	Annoyance increases at higher levels
night-time	45	Difficulties in falling asleep at higher levels
Indoor/domestic		
daytime	45	Speech communication deteriorates at higher levels
night-time	35	Increased awakening at higher levels

(Source: **Mohanan et al. 1989)**

Table-6.3: WHO recommended noise standard for steady background noise for different functional activities

Type of space	*Average noise level (dB(A))*
For just-acceptable speech and telephone communication (metro platforms)	65
Where speech or telephone communication is not required, but no risk to hearing (inside moving metro trains and driver's cabin)	80

(Source: **Mohanan et al. 1989)**

- ✓ With reference to the above tables, it may be concluded that A-weighted equivalent noise level for different monitoring stations at different hours were above this recommended noise level.

Potential effects of these noise levels

- ✓ Exposure to this type of high levels of noise is likely to produce annoyance on common people. It, in the long run, may also lead to permanent hearing disorders, heart diseases, lack of concentration and other health disorders to sensitive receptors.

Potential mitigative measures

- ✓ Introduction of noise barrier at each station, adjacent silence zone area of metro corridors, use of gasket for public address, ensuring proper noise insulation (by providing shielding and noise adsorption) property in the body of each rake, proper maintenance of electrical and mechanical machineries including rakes can mitigate the magnitude of metro railway noise to a reasonable extent.

Chapter-7

Future Scope of the Study

The present study may be extended in future to investigate on the following aspects:

- Noise quality study may be conducted near mid-section exhausts inside the tunnel, for availing an idea of overall ambient noise level of metro station and inside the tunnel.
- Noise of the metro rakes may be monitored during its movement through the tunnel portion, to investigate on the effect of noise at tunnel for moving metro.
- Rumbling noise of the tunnel ventilation system and distinctly audible rattling noise from ceiling panel can be measured to ascertain the contribution of these noise on background noise.
- Noise quality study can be conducted at driver's cabin under moving condition.
- Noise quality study may be conducted separately within AC/Non-AC rakes from one end coach to another extreme end coach before driver's cabin under moving and standing condition.
- Specific studies may be conducted separately for door operation, ventilation system noise, announcement noise for station alert and auxiliary electrical equipment noise within metro rakes under moving and standing condition may be at station platform or at car shed.
- Noise measurement may be conducted for various auxiliary electrical machines (alternators, compressor etc) fitted under the carriage and inside the different types of rakes (e.g- AC/Non-AC) separately.
- Background noise study may be conducted at tunnel portion.
- Noise quality study may be conducted within moving rakes, when no passengers are there for different commercial hours.
- Noise insulation for rake's bodies also be examined for different rakes (AC/Non-AC) under different conditions (e.g.- door open/close)
- Noise quality study may also be conducted for different speed condition inside the rakes.
- Noise quality study may be conducted under different meteorological conditions at different monitoring stations.
- Rail-wheel contact noise may also be evaluated separately by using, the formula- $L_{Awr} = 30\log(V/V_0)+60$ dB, where, L_{Awr} is normalized A-weighted SPL at a distance of 25 m, V is the rail car speed in km/hr and V_0 is the reference speed 24km/hr.
- Traction motor noise (L_{Atm}) and gear noise (L_{Ag}) may be estimated using following relationship- $L_{Atm}= 60\log V+C_1$ and $L_{Ag}= 10\log V+ C_2$, where C_1 and C_2 are constants- $C_1= -4.6$ at 32km/hr and $C_2= 66.7$ at 56 km/hr.

- Separate background noise may be monitored at driver's cabin.
- Noise exposure may be considered for passenger, worker and other exposed people belonging to different age groups by calculating Noise Dose (ND).
- Reverberation time for underground and overground stations may also be measured.
- Noise quality may be monitored at residential building near single line noise source (here, metro railway).
- Using noise data health study, epidemiological study and dose-response study may be carried out.
- It may be developed a model to predict noise level from observed data (like, rake number, type of rake etc.).

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Annexure

Table-1: Correlation matrix of average noise data of Dumdum Metro Railway Station

		n	L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
n	Pearson Correlation	1.00										
L_{eq}	Pearson Correlation	0.91	1.00									
L_{max}	Pearson Correlation	0.48	0.78	1.00								
L_{min}	Pearson Correlation	0.23	-0.20	-0.63	1.00							
L_1	Pearson Correlation	.961*	0.77	0.33	0.46	1.00						
L_{10}	Pearson Correlation	0.67	0.89	0.76	-0.53	0.44	1.00					
L_{50}	Pearson Correlation	0.77	0.88	0.89	-0.20	0.71	0.67	1.00				
L_{90}	Pearson Correlation	0.72	0.47	0.17	0.66	0.88	0.02	0.60	1.00			
L_{99}	Pearson Correlation	0.63	0.26	-0.19	0.88	0.82	-0.15	0.28	0.92	1.00		
NC	Pearson Correlation	0.35	0.65	0.64	-0.75	0.07	0.92	0.39	-0.37	-0.49	1.00	
TNI	Pearson Correlation	0.43	0.72	0.68	-0.71	0.16	.955*	0.46	-0.28	-0.42	.996**	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-2: Correlation matrix of average noise data of Netaji Metro Railway Station

		n	L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
n	Pearson Correlation	1.00										
L_{eq}	Pearson Correlation	-0.09	1.00									
L_{max}	Pearson Correlation	-0.16	.975*	1.00								
L_{min}	Pearson Correlation	-0.06	0.84	0.93	1.00							
L_1	Pearson Correlation	-0.11	0.93	0.84	0.59	1.00						
L_{10}	Pearson Correlation	-0.08	.979*	.996**	0.94	0.84	1.00					
L_{50}	Pearson Correlation	-0.18	0.93	.990*	.971*	0.75	.983*	1.00				
L_{90}	Pearson Correlation	-0.08	0.83	0.93	1.000**	0.57	0.93	.968*	1.00			
L_{99}	Pearson Correlation	-0.04	0.81	0.91	.998**	0.55	0.91	.956*	.999**	1.00		
NC	Pearson Correlation	-0.02	0.59	0.40	0.06	0.84	0.41	0.27	0.04	0.01	1.00	
TNI	Pearson Correlation	-0.05	0.92	0.81	0.56	.998**	0.82	0.72	0.54	0.52	0.86	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-3: Correlation matrix of average noise data of Belgachia Metro Railway Station

		n	L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
n	Pearson Correlation	1.00										
L_{eq}	Pearson Correlation	0.87	1.00									
L_{max}	Pearson Correlation	0.83	0.58	1.00								
L_{min}	Pearson Correlation	-0.23	-0.12	0.22	1.00							
L_1	Pearson Correlation	0.76	0.89	0.72	0.34	1.00						
L_{10}	Pearson Correlation	0.83	0.87	0.83	0.31	.983*	1.00					
L_{50}	Pearson Correlation	0.76	0.89	0.28	-0.54	0.58	0.55	1.00				
L_{90}	Pearson Correlation	0.51	0.52	0.78	0.72	0.85	0.87	0.08	1.00			
L_{99}	Pearson Correlation	-0.34	-0.29	0.16	.983*	0.18	0.17	-0.68	0.63	1.00		
NC	Pearson Correlation	0.87	0.91	0.82	0.23	.980*	.996**	0.62	0.82	0.08	1.00	
TNI	Pearson Correlation	0.86	0.90	0.82	0.25	.982*	.998**	0.60	0.84	0.10	1.000**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-4: Correlation matrix of average noise data of Shyambazar Metro Railway Station

		n	L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
n	Pearson Correlation	1.00										
L_{eq}	Pearson Correlation	0.50	1.00									
L_{max}	Pearson Correlation	0.12	-0.20	1.00								
L_{min}	Pearson Correlation	-0.17	-0.77	0.77	1.00							
L_1	Pearson Correlation	0.79	0.87	-0.33	-0.72	1.00						
L_{10}	Pearson Correlation	0.51	.980*	-0.38	-0.86	0.92	1.00					
L_{50}	Pearson Correlation	0.69	.966*	-0.03	-0.62	0.91	0.93	1.00				
L_{90}	Pearson Correlation	0.52	0.90	0.24	-0.43	0.71	0.81	0.93	1.00			
L_{99}	Pearson Correlation	-0.17	-0.58	0.91	.951*	-0.67	-0.72	-0.44	-0.17	1.00		
NC	Pearson Correlation	0.44	0.88	-0.63	-.957*	0.89	.956*	0.80	0.60	-0.89	1.00	
TNI	Pearson Correlation	0.46	0.92	-0.55	-0.94	0.91	.979*	0.85	0.67	-0.85	.996**	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-5: Correlation matrix of average noise data generated from continuous monitoring at school building (Swami Pranabananda Vidyapith (near Netaji Metro) heavily exposed by metro noise at different hours

		n	L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
n	Pearson Correlation	1.00										
L_{eq}	Pearson Correlation	-0.09	1.00									
L_{max}	Pearson Correlation	-0.16	.975*	1.00								
L_{min}	Pearson Correlation	-0.06	0.84	0.93	1.00							
L_1	Pearson Correlation	-0.11	0.93	0.84	0.59	1.00						
L_{10}	Pearson Correlation	-0.08	.979*	.996**	0.94	0.84	1.00					
L_{50}	Pearson Correlation	-0.18	0.93	.990*	.971*	0.75	.983*	1.00				
L_{90}	Pearson Correlation	-0.08	0.83	0.93	1.000**	0.57	0.93	.968*	1.00			
L_{99}	Pearson Correlation	-0.04	0.81	0.91	.998**	0.55	0.91	.956*	.999**	1.00		
NC	Pearson Correlation	-0.02	0.59	0.40	0.06	0.84	0.41	0.27	0.04	0.01	1.00	
TNI	Pearson Correlation	-0.05	0.92	0.81	0.56	.998**	0.82	0.72	0.54	0.52	0.86	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-6: Correlation matrix of average noise data generated from continuous monitoring at residential building (near Dumdum Metro Railway Station) heavily exposed by metro noise and EMU noise at different hours :

		n	L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
n	Pearson Correlation	1.00										
L_{eq}	Pearson Correlation	-0.75	1.00									
L_{max}	Pearson Correlation	-0.76	0.90	1.00								
L_{min}	Pearson Correlation	-0.46	0.48	0.81	1.00							
L_1	Pearson Correlation	-0.24	0.37	-0.06	-0.64	1.00						
L_{10}	Pearson Correlation	-0.19	-0.10	-0.42	-0.77	0.79	1.00					
L_{50}	Pearson Correlation	-0.77	0.17	0.31	0.30	-0.06	0.31	1.00				
L_{90}	Pearson Correlation	-0.36	0.11	0.53	0.89	-0.82	-0.65	0.51	1.00			
L_{99}	Pearson Correlation	-0.42	0.31	0.69	.976*	-0.74	-0.74	0.40	.970*	1.00		
NC	Pearson Correlation	0.16	-0.11	-0.53	-0.93	0.88	0.86	-0.21	-0.95	-.963*	1.00	
TNI	Pearson Correlation	0.12	-0.11	-0.52	-0.92	0.88	0.89	-0.15	-0.92	-0.95	.998**	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-7: Correlation matrix of instantaneous noise data generated from AC rakes at Dumdum Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	0.01	1.00								
L_{min}	Pearson Correlation	0.89	-0.40	1.00							
L_1	Pearson Correlation	0.81	0.35	0.49	1.00						
L_{10}	Pearson Correlation	.995**	0.10	0.84	0.85	1.00					
L_{50}	Pearson Correlation	.972*	-0.21	.974*	0.67	0.94	1.00				
L_{90}	Pearson Correlation	.959*	-0.17	.973*	0.61	0.93	.990**	1.00			
L_{99}	Pearson Correlation	0.94	-0.31	.990*	0.60	0.90	.994**	.982*	1.00		
NC	Pearson Correlation	-0.15	0.73	-0.57	0.45	-0.06	-0.37	-0.42	-0.44	1.00	
TNI	Pearson Correlation	0.54	0.65	0.11	0.92	0.61	0.33	0.28	0.25	0.75	1.00

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table-8: Correlation matrix of instantaneous noise data generated from Non-AC rakes at Dumdum Metro Railway Station:

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	-0.37	1.00								
L_{min}	Pearson Correlation	0.82	0.22	1.00							
L_1	Pearson Correlation	0.55	-.980*	-0.03	1.00						
L_{10}	Pearson Correlation	0.82	-0.80	0.39	0.89	1.00					
L_{50}	Pearson Correlation	.977*	-0.17	0.92	0.36	0.69	1.00				
L_{90}	Pearson Correlation	0.46	0.52	0.74	-0.36	-0.12	0.61	1.00			
L_{99}	Pearson Correlation	0.38	-0.29	0.12	0.36	0.20	0.34	0.50	1.00		
NC	Pearson Correlation	-0.13	-0.74	-0.53	0.63	0.45	-0.31	-0.94	-0.38	1.00	
TNI	Pearson Correlation	-0.04	-0.79	-0.46	0.69	0.53	-0.22	-0.90	-0.34	.995**	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-9: Correlation matrix of instantaneous noise data generated from combination of AC & Non-AC rakes at Dumdum Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	-0.54	1.00								
L_{min}	Pearson Correlation	0.94	-0.27	1.00							
L_1	Pearson Correlation	-0.53	.983*	-0.30	1.00						
L_{10}	Pearson Correlation	0.94	-0.22	.995**	-0.24	1.00					
L_{50}	Pearson Correlation	.965*	-0.74	0.84	-0.73	0.82	1.00				
L_{90}	Pearson Correlation	0.92	-0.81	0.78	-0.81	0.75	.992**	1.00			
L_{99}	Pearson Correlation	0.94	-0.32	.997**	-0.36	.984*	0.86	0.80	1.00		
NC	Pearson Correlation	-0.83	0.92	-0.63	0.91	-0.60	-0.95	-.979*	-0.66	1.00	
TNI	Pearson Correlation	-0.78	0.95	-0.56	0.94	-0.52	-0.91	-.957*	-0.60	.996**	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-10: Correlation matrix of instantaneous noise data generated from AC rakes at Netaji Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	.995**	1.00								
L_{min}	Pearson Correlation	-0.74	-0.67	1.00							
L_1	Pearson Correlation	.992**	.991**	-0.72	1.00						
L_{10}	Pearson Correlation	.998**	.994**	-0.74	.998**	1.00					
L_{50}	Pearson Correlation	0.79	0.82	-0.32	0.85	0.81	1.00				
L_{90}	Pearson Correlation	-0.10	-0.16	-0.40	-0.03	-0.06	-0.01	1.00			
L_{99}	Pearson Correlation	-0.86	-0.80	.979*	-0.83	-0.85	-0.45	-0.25	1.00		
NC	Pearson Correlation	0.85	0.88	-0.36	0.81	0.83	0.65	-0.61	-0.54	1.00	
TNI	Pearson Correlation	0.91	0.93	-0.45	0.87	0.89	0.70	-0.51	-0.62	.993**	1.00

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table-11: Correlation matrix of instantaneous noise data generated from Non-AC rakes at Netaji Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	0.87	1.00								
L_{min}	Pearson Correlation	0.51	0.53	1.00							
L_1	Pearson Correlation	0.79	.988*	0.55	1.00						
L_{10}	Pearson Correlation	0.88	0.55	0.20	0.41	1.00					
L_{50}	Pearson Correlation	0.81	0.71	0.91	0.68	0.58	1.00				
L_{90}	Pearson Correlation	0.56	0.85	0.75	0.91	0.10	0.70	1.00			
L_{99}	Pearson Correlation	0.24	0.68	0.39	0.78	-0.24	0.28	0.88	1.00		
NC	Pearson Correlation	-0.18	-0.59	-0.63	-0.70	0.31	-0.43	-0.92	-0.94	1.00	
TNI	Pearson Correlation	-0.06	-0.49	-0.58	-0.61	0.43	-0.34	-0.86	-0.92	.993**	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-12: Correlation matrix of instantaneous noise data generated from AC rakes at Belgachia Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	TNI	NC
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	0.61	1.00								
L_{min}	Pearson Correlation	0.39	-0.32	1.00							
L_1	Pearson Correlation	0.52	.993**	-0.43	1.00						
L_{10}	Pearson Correlation	1.000**	0.61	0.38	0.53	1.00					
L_{50}	Pearson Correlation	0.62	-0.23	0.89	-0.34	0.61	1.00				
L_{90}	Pearson Correlation	0.40	-0.35	.997**	-0.46	0.39	0.92	1.00			
L_{99}	Pearson Correlation	0.23	-0.26	0.94	-0.36	0.22	0.69	0.91	1.00		
TNI	Pearson Correlation	0.04	0.67	-0.90	0.75	0.05	-0.70	-0.90	-0.88	1.00	
NC	Pearson Correlation	0.20	0.75	-0.82	0.82	0.21	-0.59	-0.82	-0.83	.988*	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table-13: Correlation matrix of instantaneous noise data generated from Non-AC rakes at Belgachia Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	.961*	1.00								
L_{min}	Pearson Correlation	0.67	0.81	1.00							
L_1	Pearson Correlation	.964*	.963*	0.62	1.00						
L_{10}	Pearson Correlation	.972*	.983*	0.69	.996**	1.00					
L_{50}	Pearson Correlation	0.85	0.90	0.93	0.76	0.81	1.00				
L_{90}	Pearson Correlation	0.82	0.92	.974*	0.78	0.83	.975*	1.00			
L_{99}	Pearson Correlation	0.68	0.83	.999**	0.65	0.71	0.93	.978*	1.00		
NC	Pearson Correlation	0.08	-0.08	-0.65	0.19	0.10	-0.46	-0.47	-0.62	1.00	
TNI	Pearson Correlation	0.50	0.37	-0.24	0.61	0.53	-0.03	-0.03	-0.21	0.90	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-14: Correlation matrix of instantaneous noise data generated from combination of AC & Non-AC rakes at Belgachia Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	0.42	1.00								
L_{min}	Pearson Correlation	0.49	0.01	1.00							
L_1	Pearson Correlation	0.05	0.56	-0.78	1.00						
L_{10}	Pearson Correlation	0.49	0.79	-0.39	0.88	1.00					
L_{50}	Pearson Correlation	0.80	0.01	0.87	-0.56	-0.12	1.00				
L_{90}	Pearson Correlation	0.60	-0.23	0.92	-0.77	-0.40	.957*	1.00			
L_{99}	Pearson Correlation	0.59	-0.03	.987*	-0.76	-0.35	0.94	.964*	1.00		
NC	Pearson Correlation	-0.36	0.43	-0.89	0.91	0.63	-0.84	-.963*	-0.92	1.00	
TNI	Pearson Correlation	-0.29	0.47	-0.87	0.93	0.69	-0.80	-0.94	-0.89	.997**	1.00

Table-15: Correlation matrix of instantaneous noise data generated from AC rakes at Shyambazar Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	.989*	1.00								
L_{min}	Pearson Correlation	.971*	.990*	1.00							
L_1	Pearson Correlation	0.45	0.31	0.30	1.00						
L_{10}	Pearson Correlation	0.45	0.32	0.31	1.000**	1.00					
L_{50}	Pearson Correlation	0.66	0.54	0.48	0.88	0.87	1.00				
L_{90}	Pearson Correlation	0.76	0.65	0.61	0.90	0.89	.979*	1.00			
L_{99}	Pearson Correlation	0.75	0.68	0.72	0.83	0.84	0.72	0.84	1.00		
NC	Pearson Correlation	-0.12	-0.24	-0.20	0.79	0.79	0.42	0.44	0.54	1.00	
TNI	Pearson Correlation	0.12	-0.02	0.01	0.92	0.92	0.63	0.65	0.70	.967*	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-16: Correlation matrix of instantaneous noise data generated from Non-AC rakes at Shyambazar Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	0.67	1.00								
L_{min}	Pearson Correlation	-0.23	0.29	1.00							
L_1	Pearson Correlation	0.85	0.19	-0.41	1.00						
L_{10}	Pearson Correlation	0.89	0.34	-0.65	0.90	1.00					
L_{50}	Pearson Correlation	.964*	0.61	-0.45	0.81	.952*	1.00				
L_{90}	Pearson Correlation	0.95	0.82	-0.22	0.65	0.82	.954*	1.00			
L_{99}	Pearson Correlation	0.13	0.75	0.16	-0.39	-0.05	0.20	0.44	1.00		
NC	Pearson Correlation	0.68	-0.04	-0.79	0.88	0.93	0.77	0.54	-0.36	1.00	
TNI	Pearson Correlation	0.76	0.08	-0.76	0.90	.967*	0.84	0.64	-0.26	.992**	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-17: Correlation matrix of instantaneous noise data generated from combination of AC & Non-AC rakes at Shyambazar Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	0.85	1.00								
L_{min}	Pearson Correlation	0.94	0.98	1.00							
L_1	Pearson Correlation	1.00	0.89	0.96	1.00						
L_{10}	Pearson Correlation	1.00	0.80	0.91	0.99	1.00					
L_{50}	Pearson Correlation	0.99	0.92	0.98	.997*	0.97	1.00				
L_{90}	Pearson Correlation	.999*	0.83	0.92	0.99	.999*	0.98	1.00			
L_{99}	Pearson Correlation	0.98	0.94	0.99	0.99	0.96	.999*	0.97	1.00		
NC	Pearson Correlation	0.93	0.61	0.75	0.90	0.96	0.87	0.95	0.84	1.00	
TNI	Pearson Correlation	0.99	0.75	0.87	0.97	1.00	0.95	0.99	0.93	0.98	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

Table-18: Correlation matrix of instantaneous noise data generated from AC at a residential building near Dumdum Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	-0.74	1.00								
L_{min}	Pearson Correlation	0.20	0.08	1.00							
L_1	Pearson Correlation	-0.54	0.50	-0.82	1.00						
L_{10}	Pearson Correlation	.964*	-0.88	0.01	-0.47	1.00					
L_{50}	Pearson Correlation	.987*	-0.75	0.33	-0.67	0.94	1.00				
L_{90}	Pearson Correlation	0.22	0.05	.999**	-0.84	0.03	0.35	1.00			
L_{99}	Pearson Correlation	0.10	0.17	.995**	-0.77	-0.09	0.24	.992**	1.00		
NC	Pearson Correlation	0.48	-0.62	-0.76	0.33	0.64	0.36	-0.74	-0.82	1.00	
TNI	Pearson Correlation	0.60	-0.71	-0.65	0.20	0.75	0.49	-0.64	-0.72	.989*	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-19: Correlation matrix of instantaneous noise data generated from Non-AC at a residential building near Dumdum Metro Railway Station

		L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
L_{eq}	Pearson Correlation	1.00									
L_{max}	Pearson Correlation	-0.13	1.00								
L_{min}	Pearson Correlation	0.95	0.11	1.00							
L_1	Pearson Correlation	0.34	0.80	0.61	1.00						
L_{10}	Pearson Correlation	.982*	-0.28	0.87	0.16	1.00					
L_{50}	Pearson Correlation	0.77	-0.50	0.75	0.11	0.77	1.00				
L_{90}	Pearson Correlation	0.86	0.35	.970*	0.77	0.75	0.58	1.00			
L_{99}	Pearson Correlation	0.95	0.11	1.000**	0.60	0.87	0.75	.969*	1.00		
NC	Pearson Correlation	0.70	-0.71	0.44	-0.44	0.82	0.63	0.24	0.45	1.00	
TNI	Pearson Correlation	0.83	-0.59	0.60	-0.25	0.92	0.70	0.43	0.61	.981*	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table-20: Correlation matrix of noise data generated from noise monitoring within AC rakes

		n	L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
n	Pearson Correlation	1.00										
L_{eq}	Pearson Correlation	0.17	1.00									
L_{max}	Pearson Correlation	0.72	0.47	1.00								
L_{min}	Pearson Correlation	-0.21	0.25	-0.61	1.00							
L_1	Pearson Correlation	0.53	0.90	0.54	0.33	1.00						
L_{10}	Pearson Correlation	0.16	**.970***	0.31	0.47	0.92	1.00					
L_{50}	Pearson Correlation	-0.39	0.82	-0.07	0.52	0.57	0.85	1.00				
L_{90}	Pearson Correlation	-0.24	0.81	-0.13	0.71	0.68	0.90	**.958***	1.00			
L_{99}	Pearson Correlation	-0.43	0.69	-0.31	0.74	0.51	0.79	**.957***	**.977***	1.00		
NC	Pearson Correlation	0.63	-0.61	0.36	-0.60	-0.32	-0.66	**-.951***	-0.90	**-.962***	1.00	
TNI	Pearson Correlation	0.76	-0.46	0.48	-0.57	-0.14	-0.52	-0.88	-0.81	-0.91	**.984***	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

Table-21: Correlation matrix of noise data generated from noise monitoring within Non-AC rakes

		n	L_{eq}	L_{max}	L_{min}	L_1	L_{10}	L_{50}	L_{90}	L_{99}	NC	TNI
n	Pearson Correlation	1.00										
L_{eq}	Pearson Correlation	0.37	1.00									
L_{max}	Pearson Correlation	0.21	0.95	1.00								
L_{min}	Pearson Correlation	-0.47	0.62	0.65	1.00							
L_1	Pearson Correlation	0.62	.957*	0.88	0.37	1.00						
L_{10}	Pearson Correlation	0.52	.966*	0.84	0.51	.969*	1.00					
L_{50}	Pearson Correlation	-0.27	0.79	0.87	0.93	0.59	0.64	1.00				
L_{90}	Pearson Correlation	-0.45	0.60	0.58	.989*	0.35	0.51	0.87	1.00			
L_{99}	Pearson Correlation	-0.51	0.57	0.58	.996**	0.31	0.46	0.89	.996**	1.00		
NC	Pearson Correlation	0.75	-0.26	-0.30	-0.91	0.03	-0.15	-0.72	-0.93	-0.94	1.00	
TNI	Pearson Correlation	0.84	-0.12	-0.18	-0.85	0.17	0.00	-0.63	-0.86	-0.88	.989*	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).