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ARTICLES

INFORMATION

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Characterization of Honking Noise in Urban Environment of Nagpur

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ABSTRACT

India where festivals and functions are incomplete without blare sound of loudspeakers in every nook and corner introduces noise as a pollutant in the environment. Contributing to such activities, major sources of noise seeks to be the traffic noise which also entails noise produced by constant honking scenario of the vehicles. Due to existing heterogeneous condition of traffic scenario in India, the research was carried out on National highway whichemphasis on characterization of traffic and honking noise. Traffic volume, noise metrics with statistical indicators (L_{eq}, L_{10}, L_{90}, L_{max}, L_{min}) were observed during morning, afternoon and evening session. Study includes manual quantification of honking incident of different categories of vehicle (light and medium), which exhibit positive relationship with observed L_{eq} level. As per traffic volume data collected, 60-64% light category vehicles contributed 60-70% honks and medium category vehicle volume of 29-32% contributing 30-40% of honks. Statistical analysis and frequency spectrum analysis of traffic noise confirmed contribution of additional noise of 4-5.3 dB (A) due to honking. Different octave bands were simultaneously compared with audio waveform confirming numerous octave bands contributions on honking event. Honking by light category vehicle was found dominant in 4000 Hz band whereas medium category vehicle honking response was observed in 2000Hz band. The sound pressure showed increment of 67-84% due to honking noise from vehicles, with single honk occurring every 3 seconds in the traffic. The noise levels were beyond the statutory limit established by Indian and International standards. With characterization of honking noise in this research, further noise abatement measures and guidelines can be formulated, developed and implemented.

1. INTRODUCTION

Due to unique source and diffusion properties, noise pollutant is emerging as a new challenge for society[1]. Out of total urban noise, 55% of noise exist due to vehicular traffic[2-4]. With 2100 lakhs (2015) registered vehicles on Indian roads, the amount of traffic noise induced by such heavy vehicular volume is beyond imagination. Honking with purpose of attention seeking, gratitude expression, danger alert also incorporates a way for pouring of anger of driver, which effects negatively on pedestrians by vexed volume and quality of horns[5]. With increase in vehicular volume, there is increment of worthless honking contributed by vehicle at intersection during red signal[6], the scenario get worsen in a gridlock environment. Honking episode adds 1-4 dB(A) above prevailing traffic noise level[7]. Adverse effects of traffic noise on human performance and efficiency have been observed including complications like headache, fatigue, stress and poor concentration[9]. Besides traffic volume other factors like vehicular speed, road geometry also contributes to the traffic noise[8]. Many researchers have characterized the traffic noise with help of noise metrics and statistical indicators[7,10]. Very rare attempts have been enforced with intention of honking noise characterization. Noise is responsible for physiological effects as well as psychological disorders. Inclusion of noise in the workplace results in increment of tension and behavioral aggression[11]. The society reaction to traffic noise emerges to be revenue bias which entails inclusion of socio-economic balance of community for abatement measures regarding noise laws and regulations. With low discipline towards noise abatement, peoples are compelled towards road traffic noise adaptation[12]. Negative effect of noise can be observed if exposure to noise is persistent. Long exposure to sound level of 75-85 dB(A) or acute exposure to impulse sound results in noise induced hearing loss[13]. Drivers in distractions14 requires numerous honks, before their attention can be gained hence enforcing other driver to honk more than regular, resulting in hike in noise level. With characterization of honking noise, its abatement measures can be planned and devised accordingly. The study concentrates on traffic and honking noise contributed by different categories of vehicle (light and medium vehicle) in urban environment of Nagpur, India which also involves statistical and octave band analysis for closure of research. Frequency spectrum analysis can be utilized for modification in acoustic properties of different category of vehicle horns.

2. METHODOLOGY

Nagpur being listed third in Maharashtra urban centers also accounts for health care hub of the state. With 6% population of state residing in Nagpur also incorporates as second capital of Maharashtra[15]. With area of 217.65 sq.km. lying between latitude 215'1" to 21 11'43"N and longitude 7859'27" to 79 10'4" constitutes of two major national highway namely NH-7 (Kanyakumari-Varanasi) and NH-6 (Hajira-Kolkata) passing from vicinity of city[7]. Research area comprise of a single location on National Highway 7 (Wardha Road) in front of National Environmental Engineering Research Institute (NEERI, Nagpur) (Fig. 1). Road of asphalt surface consist of 4 lanes with total width of 21 m, separated by road divider for avoidance of mixed traffic flow[8] with metro flyover (under construction) approximately 12-14 m above the road level. The total vehicular population of Nagpur is 12.9 lakhs, out of which II wheelers vehicle accounts for 83.4% (1082447) of total vehicular volume [16]. The study proceeds in two phases namely section I for data collection of traffic noise, vehicular volume with honking scenario and later advances into section II involving data analysis with purpose of characterization of honking noise in urban environment.

3. DATA COLLECTION

Many researches have been carried out with sampling period of 60 minutes with corresponding interval depending on objective of the study[1,17-19]. For assessment of traffic and industrial noise in India, analysis of 15 minutes of noise and traffic data was scrutinized[3,7,20-22]. For statistical analysis, data which can be related most with prevailing field conditions, noise level and traffic data with honking characteristics were collected in three sessions i.e. morning (0900-1100), afternoon (1300-1500) and evening (1700-1900) with time interval of 1 second. Hence noise level, traffic data and honking incidents of 7200 seconds per shift were analyzed. For assessment of honking noise with help of octave bands, octave band data was retrieved with same timeframe as stated above. For *characterization* of honking incident, octave band data of 300 seconds with time interval of 1s was analyzed per shift. For enhancement of octave band analysis, sound waveform of 60 seconds was generated with help of digital camera video recording sound.

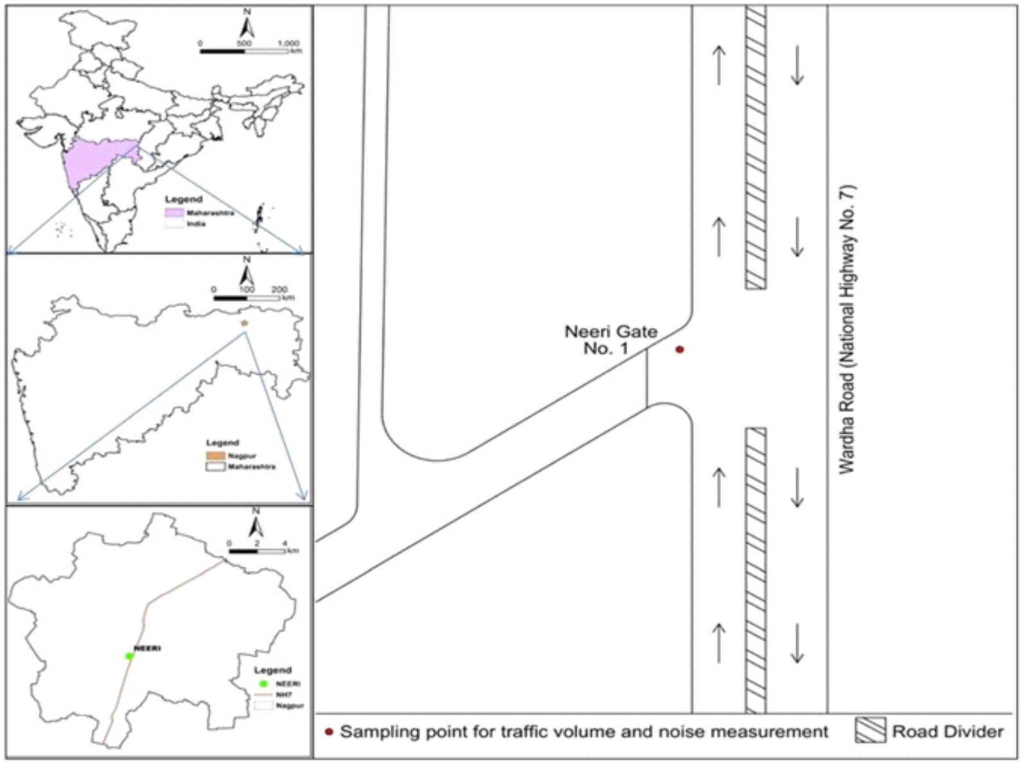

Fig. 1. Base map of study area and sampling location

3.1 Road traffic noise

Evaluation of noise level was accomplished with help of Type-I sound meter (Sound Pro SP-DL1) under fast response with time interval of 1s. Instrument was mounted on a tripod with height of 1.5 m above the ground while making sure that no vibration or ambience activity disturbs the instrument. Sound meter is attached with foam windshield for minimization of disturbance in noise level generated by wind. Instrumentation was conducted according to standard method[23-24]. Traffic noise was dissected under "A-weighted" sound pressure which resembles human ear response to sound. Noise metric such as Leq, L_{max}, L_{min}, L_{10} and L_{90} are denoted by sound meter with corresponding octave band readings respectively.

3.2 Traffic volume and honking

With sound meter, digital camera (Fujifilm Fine pix S3300) was simultaneously mounted on a tripod and positioned such that efficient coverage of vehicle passing from intersection can be achieved. Vehicular volume was quantified manually with help of video recording playback on computer system. In same manner number of honks of different category of vehicles were manually heard and evaluated. Confirmation of honking was assessed by simultaneously running video playback and observing fluctuating noise level on a computer system. Vehicular volume was divide into 4 categories *viz.* light(scooter, motorcycle, moped), medium(car, jeep),heavy(bulldozer, truck, dumper, bus,) and auto-rickshaw. For comparison of vehicular noise with respect to common datum, passenger car noise unit (PCNU) was utilized which represents the factor by which other vehicles are noisier when related with passenger car4.For observing dominance of different octave bands, sound waveform was generated and honking of different category of vehicle (light and medium) were manually marked for 60 second timeframe while making sure that sound waveform and honks marking belongs to same timeline.

4. DATA ANALYSIS

Noise metrics L_{eq}, L_{max}, L_{min} , L_{10} and L_{90} were derived with help of measured noise level. Traffic volume, PCNU, octave bands data were further analyzed for characterization of traffic 00and honking noise in this section.

4.1 Traffic noise index (TNI) and noise exceedance factor (NEF)

Total noise index is enclosed by combining the effects of maximum level of noise (L_{10}) and average level of background noise (L_{90}) which conveys the resident's dissatisfaction by the prevailing traffic noise condition[25] calculate as per Eq. (1).

$$TNI = 4(L_{10} - L_{90}) + (L_{90} - 30) \quad (1)$$

Noise exceedance factor (NEF) denotes the factor by which the traffic noise exceed the statutory limit calculate as per Eq. (2). In India the standard value is given by Noise Pollution (Regulation and Control) Rule 2000 as per Central Pollution Control Board, India.

$$NEF = L_{eq} / L_{REF} \quad (2)$$

L_{REF} = Permissible noise level

4.2 Sound pressure

Sound pressure (p) with respect to responding noise level were measure for different category of vehicle according to following equation Eq.(3) where p,pref equates to pressure of noise level and reference pressure value of human threshold in N/m^2 respectively. Pref equals to 2×10^{-5} N/m^2.

$$SPL(dB) = 20 \times \log^{10} (p/p_{ref}) \quad (3)$$

4.3 Statistical analysis

Coefficient of determination was evaluated to quantify dependence of total honking, light category vehicles honking, medium category vehicles honking with equivalent noise (L_{eq}). Statistically, overall contribution of honking noise, contribution of light category vehicles honking noise and contribution of medium category vehicle honking noise was evaluated.

4.4 Frequency analysis

Instrument utilizes 1/1 octave band having frequencies 8Hz, 16Hz, 31.5Hz, 63Hz, 125Hz, 250Hz, 500Hz, 1kHz, 2kHz, 4kHz, 8kHz and 16kHz respectively. With 11 octave band in audio spectrum, the measured sound level is logarithmic summation of sound level of all octave bands. Fluctuation of different octave bands in honking scenario is observed. For assessment of honking by vehicles, octave bands responding most during honks are subtracted from total noise level resulting in separation of traffic noise and honking noise. For characterization of honking noise, 60 seconds sample is selected from each shift and honks occurred by light and medium category vehicles are marked manually while confirming it with video playback on a computer system. Hence contribution of light and medium category vehicles can be computed. For confirmation of dominant octave bands in honking incident, waveform of sound is developed and compared with graph of respective octave band.

5. RESULTS AND DISCUSSION

5.1 Sound levels and traffic volume

Noise metrics (L_{eq}, L_{max}, L_{min}, L_{10} and L_{90}), traffic noise index (TNI), noise exceedance factor (NEF) with vehicular volume in PCNU of different sessions are presented in Table 1. For comparison of traffic volume against a common datum PCNU values calculated were 0.8,1.0 and 6.5 for light, medium and heavy category of vehicle. For auto rickshaw PCNU value estimated was 1.248. It is observed that even with low vehicular volume in evening session with respect to morning session, the L_{eq} of the respective session is higher which simulate that relationship between L_{eq} and vehicular volume is not invariably linear. As number of honk increases, L_{eq} level also rises and with highest number of honks in evening session, L_{eq} complies the same. The equivalent noise level (L_{eq}) is relatively low during afternoon session due to low vehicular volume and lowest honking incidents among three sessions but surpassing the statutory permissible standards for the zone. With frequency of one honk every 4(3.51-3.97) light vehicles; the light vehicle category dominates with 60-65% honking incidents and rest belonging to medium category vehicles with single honk occurrence every 3(2.52-3.15) medium vehicle. Three wheeler vehicle Auto rickshaws play an important role in public transportation in India which constitutes for 8-9% of total vehicular volume (PCNU) undertaken in this study. L_{10} and L_{90} denoting the peak sound level and background noise level respectively for evening session were 80.8 dB(A) and 70.6 dB(A) i.e. highest among other sessions. Traffic noise index for morning, afternoon and evening session were 76.5 dB(A), 77.7 dB(A) and 81.4 dB(A). Traffic noise index over 74dB (A) is sign of increasing dissatisfaction in residents exposed to traffic[26]. Noise exceedance factor was more than 1 in all sessions hence trespassing the permissible noise level. Thou difference between vehicular volume of evening and morning session is not enormous, honking number vary from a large margin hence concluding that people are honking more than normal, which might be the result of reduction in visibility. Office hours end generally in evening session where people are in constant rush to reach their destination hence increment in honking incidents can be seen. Overtaking of vehicles involves honking; maintaining smooth flow of traffic and providing separate lane for light and medium category of vehicle, number of honks during overtaking scenario can be minimized.

Table 1: Detail of honking, noise levels and traffic volume

		Noise level in dB(A)					Traffic noise index		Traffic Volume PCNU			
Session	Honks	L_{eq}	L_{10}	L_{90}	L_{max}	L_{min}	TNI	NEF	Light	Medium	Heavy	Auto
M	2441	78.1	79.5	70.5	101.9	60.6	76.5	1.20	5091	2646	2262	951
A	2235	77	78.9	69.3	97.6	58.9	77.7	1.18	3936	2225	2275	823
E	2766	78.7	80.8	70.6	99.1	61.3	81.4	1.21	4987	2745	2139	857

M=Morning A=Afternoon E=Evening PCNU=Passenger car noise unit

5.2 Statistical Analysis

Linear regression was plotted keeping equivalent noise level (L_{eq}) as dependent variable and different parameters like number of honks by light and medium category of vehicle, total number of honks as independent variables. Total noise level is the summation of traffic and honking noise when no other activity arises. Values of different parameters were calculated with frequency of 1 minute for 2 hours *i.e.* set of 120 data points were developed per shift. In Fig. 2 it can be observed that with 120 data points and heterogeneous condition of Indian traffic, the data was highly fluctuating hence coefficient of determination (R^2) was low when relating L_{eq} and honking via regression. Thus L_{eq} level corresponding to same number of honk was averaged to assess for efficient estimation of traffic and honking noise as shown in Fig. 3. Regression between L_{eq} and honking exhibited positive relationship for all three sessions. For characterization of honking, L_{eq} was regressed against honking incidents of light and medium category with R^2 value between 0.45-0.83. Maximum value of R^2 *i.e.* 0.83 was observed with medium category vehicle in the evening session. Noise level with no honking incident was concluding using abscissa value of equation developed in regression. Comparison between noise level of honking and without honking incident are shown in Table 2. In all sessions, light vehicles noise level are higher than medium vehicles except in evening where medium vehicles are noisier in terms of noise level due to higher number of

Table 2 : Detail of Leq level (with and without honking) and sound pressure

Session	Vehicle Category	HONKS	Leq dB(A) With Honk	Without Honk	Diff.	Pressure(P) (in Pascal) Without Honk	Without Honk	Diff.	% inc. in P
M	LV& MV	2441	78.1	73.6	4.5	0.09573	0.16071	0.06498	67.88
	LV	1603	78.1	75.5	2.6	0.11913	0.16071	0.04157	34.9
	MV	838	78.1	76.1	2	0.12765	0.16071	0.03305	25.89
A	LV& MV	2235	77	72.8	4.2	0.08730	0.14159	0.05420	62.18
	LV	1402	77	73.2	3.8	0.09142	0.14159	0.05017	54.88
	MV	833	77	74.8	2.2	0.10991	0.14159	0.03168	28.82
E	LV& MV	2766	78.7	73.4	5.3	0.09355	0.17220	0.07865	84.08
	LV	1679	78.7	75.3	3.4	0.11642	0.17220	0.05578	47.91
	MV	1087	78.7	74.3	4.4	0.10376	0.17220	0.06843	65.96

M=MorningA=Afternoon E=Evening LV=Light vehicle MV=Medium vehicle

honks by medium vehicles compared to other sessions. Maximum disparity in noise level was observed to be 73.4 when L_{eq} of respective session was 78.7 *i.e.* rise of 5.3 dB(A) in noise level due to honking in evening session. Honking incident raised the noise level by 4.5 dB(A) and 4.2 dB(A) with 2441, 2235 honks in morning and afternoon session respectively. Light category vehicle were responsible for 1603, 1402 and

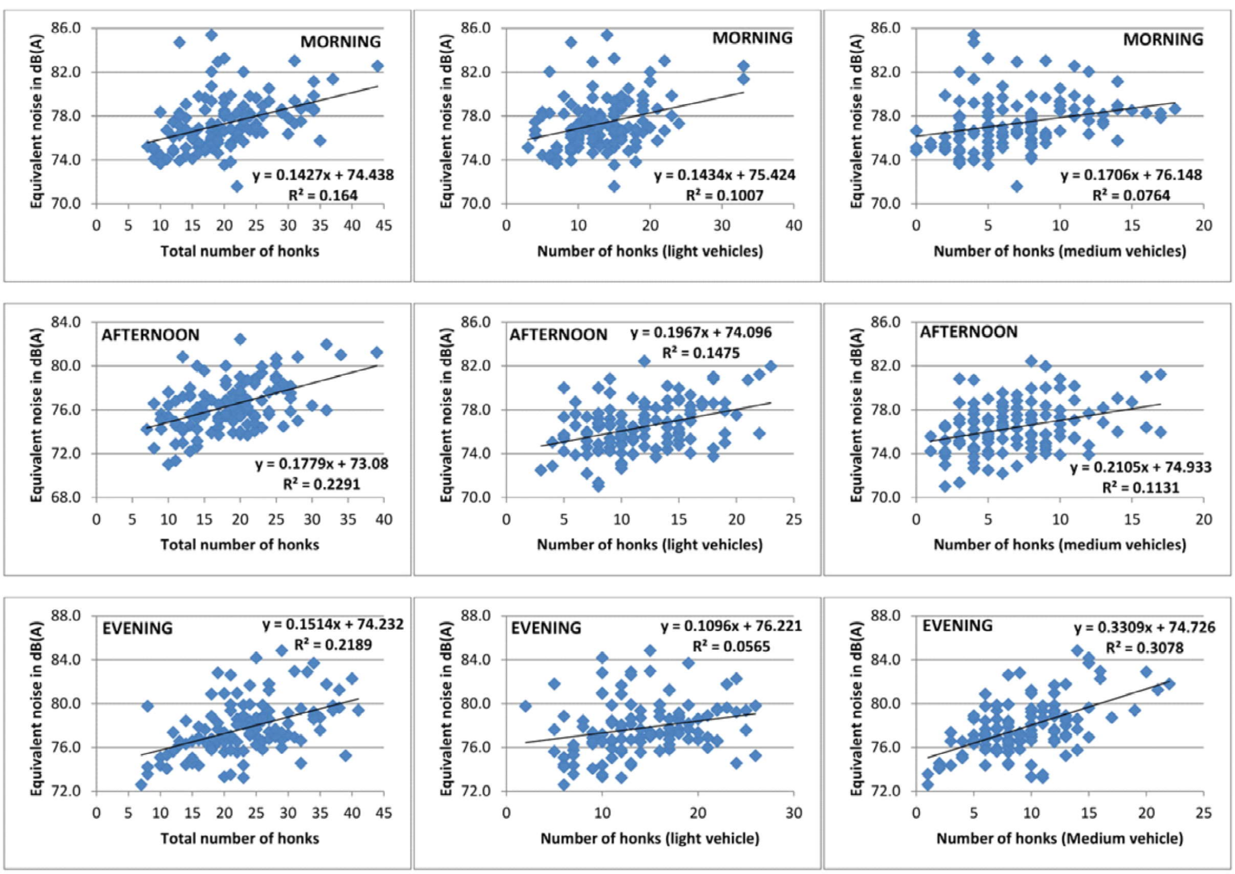

Fig. 2. Relationship between equivalent noise and honking of morning, afternoon and evening session of each 1 minute interval

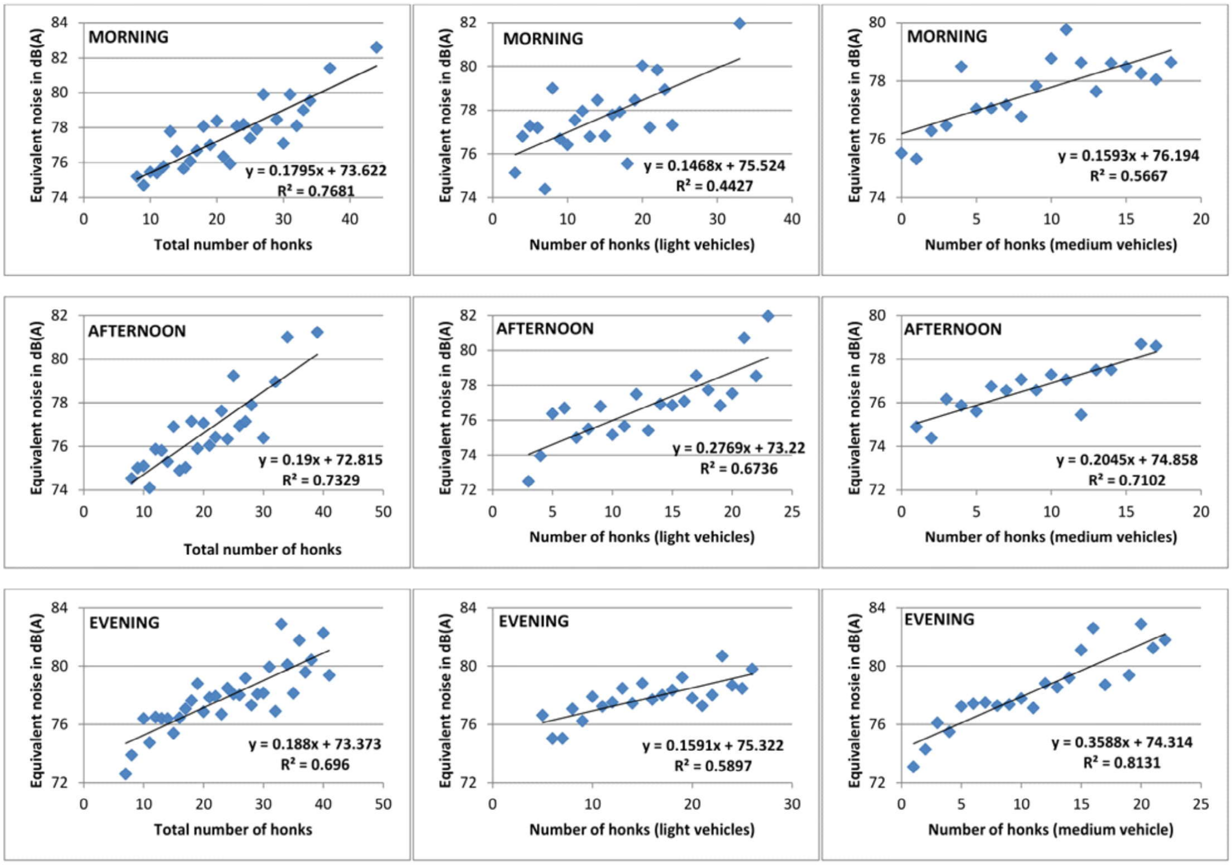

Fig. 3. Trend analysis between equivalent noise and honking based on average honking in unit time interval

1679 honks in morning, afternoon and evening session whereas medium category vehicle accounts for 838, 833 and 1087 honks in respective session.

5.3 Sound pressure

Difference in sound wave and its medium (air) pressure results in sound pressure which is expressed in Pascal (Pa) and 1 Pa = 1N/m^2. Thres hold value of sound pressure for human lies from .00002 Pa and extending to 200 Pa where every increase of 6 dB in sound level doubles the sound pressure. Sound pressure responding to noise level of honking and no honking incidents were calculated with help of equation (3) which are presented in Table 2. Highest percentage increment in sound pressure was observed in evening session with 84.08% due to honking scenario where contribution of honking raise the noise level by 5.3 dB(A). Lowest increment in sound pressure by light vehicle category was observed to be 34.90% in morning session.

5.4 Frequency analysis

Different octave band's sound level logarithmic summation leads to corresponding sound level at that instant. In honking incident different octave bands were fluctuating but 500 Hz, 2000 Hz and 4000 Hz band were highly dominant. Such high frequencies are mainly responsible for hearing impairment[27]. People's exposure to such high frequencies on daily basis via traffic and honking noise is an alarming situation which requires prevention as well as cautions. Comparing different octave bands response with help of audio waveform on a 60 second timeline reveals dominance of 4000 Hz band on light vehicle category honk's with medium vehicle category (generally cars) honks fluctuations were high in 2000 Hz band. Mixed response of 500Hz band was observed for different vehicle category honking (Fig. 4a-4c). Preeminent effects of light vehicle honking can be observed in 4000Hz band where peaks almost collide with prevailing noise level (Fig. 4c). Fluctuations in 1000Hz band was due to vehicular movement of heavy category vehicles. Rare response of band towards honking was observed hence was omitted from category of honking dominance bands.

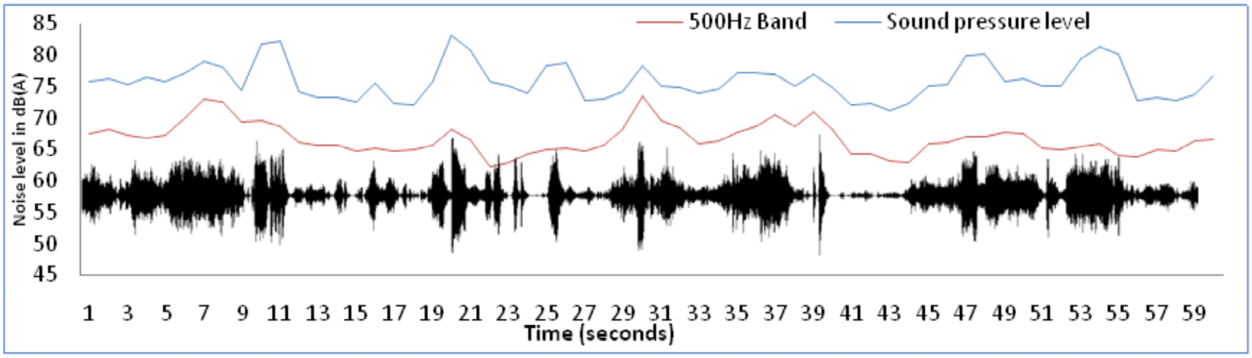

Fig. 4(a). Response of 500Hz frequency band, Sound pressure level and audio waveform

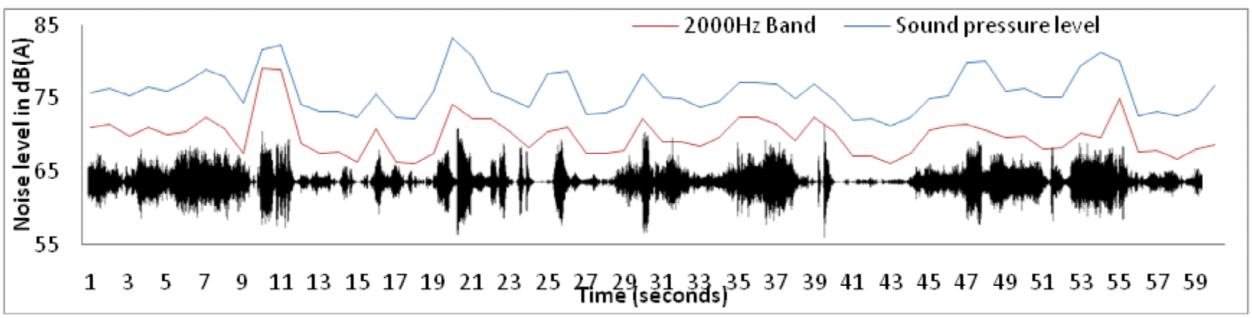

Fig. 4(b). Response of 2000Hz frequency band, Sound pressure level and audio waveform

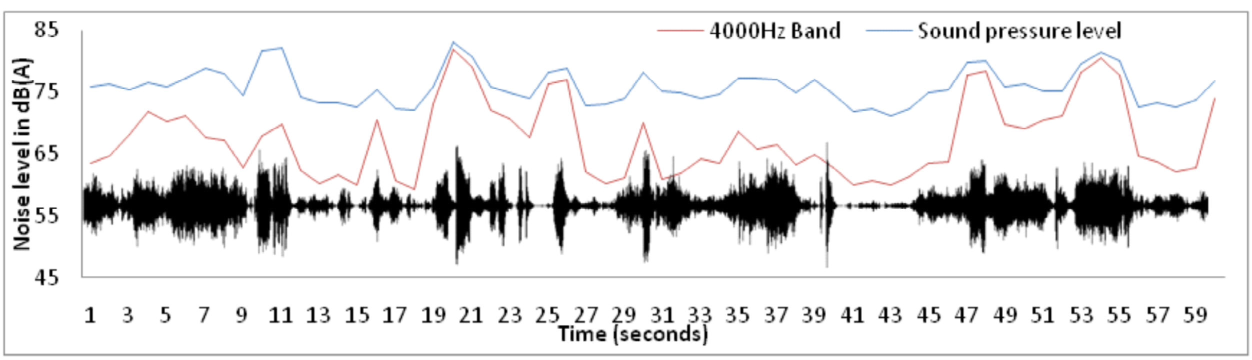

Fig. 4(c). Response of 4000Hz frequency band, Sound pressure level and audio waveform

5.5 Assessment of honking

For assessment of honking in 2 hour sampling per session, sound level of 500Hz, 2000Hz and 4000Hz band were subtracted from noise level. Average difference after removing honking dominating band was

4.1 dB (A), 4.0dB (A) and 4.4 dB (A) for morning, afternoon and evening sessions respectively. The difference ranges from 0.8-26.2 dB (A) in morning session, 0.5-23 dB (A) in afternoon session and 0.7-25.2 dB (A) in evening session.

5.6 Characterization of honking

Though sample period of 5 minutes in each session do not represent the conclusion of 120 minutes observation per session, characterization of honking in light and medium category vehicle has been attempted for minimal observation. Results reveal that out of 300 seconds, honking occurs in 30-35% of time out of which light and medium category vehicles are responsible for 20-22% and 10-13% respectively. Even with low contribution of medium category vehicle honking, Leq response is comparatively higher than light category vehicles except in evening session which might be due to long-horn pattern adopted by light category vehicles (Table 3).

Table 3 : 5 minute (300 seconds) analysis with Leq level

Session	Category	Time(s)	% share	L_{eq} dB(A)
M	Total duration	300	100	78.8
	No honking	208	69.3	76.8
	LV honking	60	20	79.9
	MV honking	32	10.7	83.5
A	Total duration	300	100	79.5
	No honking	197	65.7	75.3
	LV honking	63	21	82.6
	MV honking	40	13.3	83.3
E	Total duration	300	100	79.1
	No honking	197	65.7	75
	LV honking	66	22	82.5
	MV honking	37	12.3	82.3

M=Morning A=Afternoon E=Evening LV=Light vehicle MV=Medium vehicle

6. CONCLUSION

It is observed that honking scenario increase noise level by 4-5.3 dB (A) which is confirmed with statistical and frequency analysis as elaborated earlier. When evaluated it was evident that out of total honking incidence, 60-70% honking came from light category vehicles while medium category vehicles contributes 30-40% of total honks as shown in Fig 5. When above observations were compared using frequency analysis, it is seen that despite of low volume and less honking, medium category vehicles are found to be dominating over light category vehicles in characterization of honking. With 5.3 dB (A) contribution of honking over traffic noise, 82% increment in sound pressure have been noted in evening session. Even with low vehicular volume in evening session, Leq level for respective session is highest. Exposure to high frequency of honks, vulnerability to traffic and honking noise leads to many physiological effects and psychological disorders. Every individual get expose to traffic and honking noise for a fair share of time hence chronic effects of noise pollution can be foreseen. For precautionary measures different types horns enclosed in different category of vehicles must be standardized and fancy horns must be prohibited. Many honking incidence arises due to overtaking of vehicles irrespective of the category hence smooth flow of traffic must be rendered for minimum honking incidents. Key for less honking scenario lies within driver's patience and presence of mind.

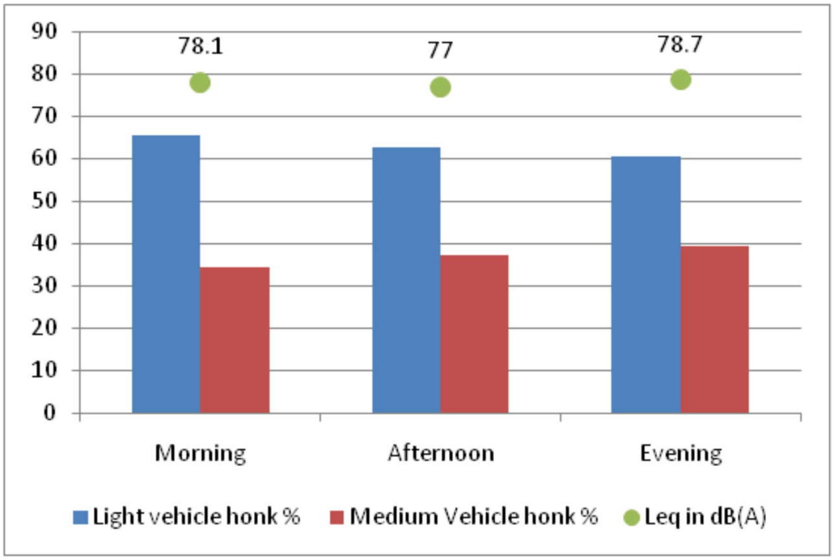

Fig. 5. Honking and Leq for different sessions

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Noise Mapping: A Scoping Review

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ABSTRACT

With advancement in civilization, there is a gradual and steady increase in the environmental noise levels and it has become a part of urban soundscape. Exposure to noise above the permissible limits may have auditory and/or non-auditory effects. There is a pressing need for an immediate action to be taken to monitor the noise levels and to keep them within the permissible limits. Noise map could be used as an excellent tool to regulate the level of noise in the environment. Development of noise maps generally involves two approaches. One is to make direct measurement of noise level for selected sites and create a map by the interpolation method. The other approach is to model noise levels by updating noise emission, propagation and reception data into geographical model of area under the study. Although both the procedures have been used in the literature, there is a lot of variation in the methodology adopted. Hence, the current review attempts to draw an ideal framework by reviewing several articles on noise mapping and discussing the pros and cons of the same.

1. INTRODUCTION

Sound is a sensory perception, and noise corresponds to an undesired sound. Sound becomes noise when it is physiologically or psychologically unwanted[1]. Noise is defined as any unwarranted disturbance within a useful frequency band[2]. Exposure to noise above the permissible limits may have auditory and/ or non-auditory effects. Auditory effects surface when the noise levels exceed the safe limit of hearing *i.e.* > 85 dB (A), causing damage to the ear structures leading to noise induced hearing loss[3]. Consequently, Temporary Threshold Shift (TTS), and Permanent Threshold Shift (PTS) are caused. Recovery from threshold shift is seen in TTS, but the threshold remains at an elated value in PTS[3]. Permanent NIHL is because of the destruction of cochlear hair cells or damage to their mechano-sensory hair bundles[4]. Noise induced tinnitus is seen following exposure to high levels of noise[5]. Non-auditory effects encompass sleep disturbances[6], performance reductions[7,8,9], abnormal endocrine responses[10], risk of cardiovascular problems[11,12,13], stress and anxiety[14].

There are several guidelines and standards given by Environmental Protection Agency (EPA), U.S. Department of Defense-Hearing conservation program (DOD-HCP), International Labour Organization (ILO), The Committee on Hearing, Biomechanics and Bioacoustics (CHABA), Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) for governing the effects of exposure to noise. OSHA (1983) recommends an exposure limit of 85 dB(A) for 16 hours per day, and a 5-dB time-intensity tradeoff[15]. For every 5 dB increment in noise level, the permissible exposure time is reduced by half and for every 5 dB decrement in noise level, the permissible exposure time is doubled. Similarly, NIOSH (1998) permits an exposure of 85 dB(A) for 8 hours per day, and uses a 3 dB time-intensity tradeoff[16].

Although a damage risk criterion has been formulated by OSHA and NIOSH, it should be noted that, both standards assume noise to be a part of work environment and consider non-occupational setting to be quiet. However, noise is a transient event which could be present during any time of the day. With advancement in civilization, noise is contributed by various sound sources such as road traffic, construction work and recreational activities which could span from day to night. Although noise is considered as a part of urban soundscape, there is an immediate call for its management, since it conflicts with a person's wellbeing and interfere with his daily routine[17]. Rapid economic growth in developing countries like India has resulted in advancement in urbanization, which poses serious noise problems, with weak conformation to noise regulations contributing to it[18]. Noise could result in potential annoyance and/or hearing loss. With noise induced hearing loss being one of the major causes of preventable hearing loss[19], there is a pressing need for an immediate action to be taken to monitor the noise levels and to keep them within the permissible limits.

1.1. Noise Mapping

Although some previous approaches have been made, the main international agreement, definitions, and basis for noise mapping were born in relation to the European Union adopted Directive 2002/49/CE20 (2002), regarding the assessment and management of environmental noise, with the target of controlling and reducing sound pollution using a standard approach and preventing the negative effects of noise exposure[20].

Noise mapping could be used as an excellent tool to regulate the noise levels in the community. A noise map is designed for assessment of noise levels in a particular area resulting from various sources like building constructions, traffic and recreation. The noise map shows the spatial distribution of noise levels in the environment. Color coding could be used to represent the level of noise and how it varies across the areas. Identification and determination of areas which are exposed to high level of noise could be done using noise mapping[21]. Using noise maps the number of citizens who are at risk of being affected by noise exposure can be determined.

Noise maps generated could be used to illustrate the level of noise in different zones, quantify the main source of noise, monitor changes in environmental noise, locate major source of noise, provide reference for noise reduction measures and policy makers, to identify population at risk and to create public awareness[18]. A noise map can be generated based on the noise levels measured either by on field measurements or through calculation procedures[20]. On field measurements include measurement of level of noise at the site of noise source using sound level measuring devices. On the other hand, calculation procedure in volves development of geographical model of area under the study and updating the noise emission data, propagation data, receptor data and applying certain calculations to estimate the level of the noise and generate a noise map[22]. Although noise maps based on measurement procedure have been commonly used in the past, calculation methods are now being adopted widely for generation of noise maps.

1.2. Application of Geographical Information System (GIS) in noise mapping

Although, several software such as Lim A, Cadn A, Sound PLAN, Predictor and FAA can be used for generation of noise maps, GIS has been widely used in many studies[18,23,24,25]. GIS is a computer based system which enables the user to collect, store, analyze and present the data spatially. As noise as a phenomenon, involves spatial distribution and is dynamic in nature, it requires a dynamic system for spatial representation of data which is supported aptly by GIS. Information can be categorized and stored in separate layers in the GIS system. Noise data obtained through the measurement process can be stored as a separate layer and can be overlapped on the existing geographical information. Tools are provided in the GIS for storing and retrieving, transforming and displaying spatial data from the real world for a dedicated purpose[26]. Manipulation of data at different stages of the process can be easily tracked down using cataloguing and metadata management system of GIS[27]. These include changes in input data, interpolation methods, calculation methods, calculation settings and other factors, which potentially influence the accuracy of results. Visual representation of noise effects is facilitated in GIS and interpolation techniques to generate noise contours are available. Therefore, GIS is considered as a potential tool in the study of the possible effects of noise pollution.

1.3. Research question:- Drawing an ideal framework for the purpose of noise mapping

In the present article, various studies on noise mapping are reviewed throwing greater focus on methodology. To draw an ideal framework of carrying out noise mapping, it is important to understand the different methods used in the literature and adopting the pros of the same.

2. METHOD

We reviewed literature to select articles related to noise pollution. Pubmed and Google scholar were searched using 'noise mapping' as the key word. All the reviewed articles were evaluated for inclusion in our study. Research studies performing noise measurements through onsite measurement methods and calculation procedures were selected for reviewing. Articles published in English were selected. However, letters and editorials were rejected. Data were extracted on study characteristics, noise mapping measurement procedures, calculation procedures, analysis of and computation o the data.

Development of noise maps generally involves two approaches. One is to make direct measurement of noise level for selected sites and create a map by the interpolation method. The other approach is to model noise levels by giving noise emission, propagation and reception data.

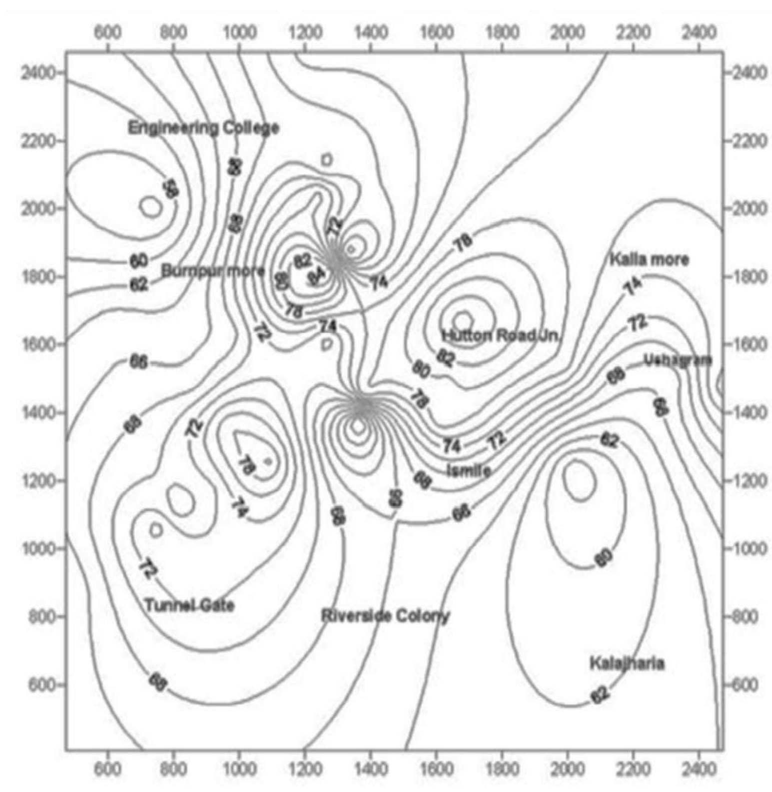

Fig. 1. Isopleth map generated from the data obtained[28]

2.1. Noise mapping through onsite measurement of noise levels

On field measurements include measurement of level of noise at the site of noise source using sound level measuring devices. It involves identification of locations, calibration and setting up of instruments, specifying duration and time frames for noise measurement.

Banerjee, Chakraborty, Bhattacharyya and Gangopadhyay (2008) measured level of road traffic noise in Asansol town of East India. 35 locations were selected in the city to measure the noise level[28]. The studyarea was classified into residential, commercial, industrial and silence/sensitive zones based on the land use pattern. A Type 2 Digital Sound Level Meter (SLM), with a frequency range of 31.5Hz to 8000Hz and measuring range between 0 - 150 dB, was used for the study. Calibration of the SLM was carried out using a 'B & K' (Bruel & Kjaer) acoustic calibrator (Model: 4226). Microphone was placed at a height of 1.5 meters from the ground level and all the recordings were done using 'A-Weighting' frequency network, and time weighting kept at 'fast' mode. All measurements were carried out during working days and under suitable climatic conditions. The following Noise Indices were computed for analysis: LAeq (Hourly A-weighted equivalent sound level), Ldn (Day-Night average sound level), Lmax and Lmin.

Table 1. Noise indices expressed in dB (A) for four different land zones (Banerjee *et al.*, 2008)[28]

	Commercial	Industrial	Residential	Sensitive
LAeq (Day)	53.0-80.5	65.7-76.7	53.6-76.8	60.8-85.6
LAeq (Night)	55.5-81.9	45.5-59.9	43.5-70.0	54.0-73.8
Ldn	66.6-87.3	66.8-78.0	53.3-79.3	67.6-81.3

From the noise level assessment carried out in the study, it was evident that the level of noise was higher than the recommended standards in all the four different land zones. The authors conclude that noise emission and transmission depend on landscape, geographical features and topography. Further, possible suggestive control methodologies are prescribed to monitor the level of noise.

Obaidat (2008) measured the level of noise due to traffic conditions in the city of Jordan and map the same using GIS[29]. Recordings were carried out at signal junctions, between signal junctions and neighborhood around the signal junctions totally at 27 locations. Measurements were carried out during three time frames: morning (07:30 to 09:00), afternoon (13:30 to 15:00) and evening (21:00 to 23:00). Noise levels were measured with the help of calibrated SLM and the distance between measured points varied from 50-100 meters. Three recordings were carried out at each location and averaged values were considered. Contour maps and spatial distribution of noise data was mapped using Arcmap GIS software. Noise levels of up to 80dB were recorded at some signals, while the lowest was 34 dB. Noise levels exceeding the prescribed standards were noted at few signal intersections across all three time frames. The obtained data were spatially displayed on a two dimensional noise map. Authors conclude that based on such maps, level of noise fora location of the study area at any point of time could be visualized and are useful for city planners to know the boundary of annoyance noise levels in any of the land use patterns.

Iaaly-Sankari, Jadayel and El-Murr (2010) measured the noise levels in the city of El-Mina, North Lebanon[23]. Study was carried out with an aim of generating noise map of the city, extent of perception of noise as a problem and to identify the noise source having greatest effect. The noise measurement was carried out at 350 locations within an area of 3.5 km². Distance between two measurement points varied from 50 to 150 meters depending on the population density. Measurement of noise was carried out at interval of 5 minutes for eight hours in a day at each measuring point and the average value was considered for GIS calculations. A survey was carried out using a questionnaire regarding the effect of noise on people. Geographical location of the measurement point was recorded using GPS. The obtained data was mapped onto GIS. A spatial database was developed containing information on noise level, noise source and impact of noise. Inverse Weighted Distance (IDW) technique was employed for surface interpolation of the noise levels.

Results of the present study revealed noise levels at around 68% of measured points to be in excess of 70 dB(A) which is greater than internationally accepted tolerable range of 60-70 dB(A). Based on the survey, all questioned individuals living in El-Mina were annoyed by the noise, which affected each individual differently. It was concluded that traffic noise was the major source of noise pollution.

King, Roland-Mieszkowski, Jason and Rainham (2012) assessed the effect of land use pattern on the level of noise in the environment30. For the purpose of the study, two areas in Halifax Regional Municipal Corporation, city of Scotia wereselected. One area was exclusively residential (Area 1), while the other had a mixed commercial-residential land use pattern (Area 2). Both the study areas were divided into 6 identical cells with the help of GIS. Noise recordings were carried out at each cell for a duration of 45 minutes at four different time frames namely morning (06:00-12:00), afternoon (12:00-18:00), evening (18:00-24:00) and night (24:00-06:00) leading to an overall measurement duration of 3 hours.

Noise measurement was carried out using a Center 322 Logging SLM and a Marantz PMD-660 Solid State Digital Recorder. The SLM and sound recorder were placed at a height of 1.5m from the ground level with the help of tripod stand. The noise recording was averaged at every one second and the results were computed in terms of equivalent continuous sound pressure level in dB (Leq) and day-evening-night composite whole-day rating level (LRden) values. Results of the present study indicated that Leq values ranged from 44.70-76.80 dB (A) in the exclusive residential area, whereas that in mixed commercial-residential area varied from 55.40-72.20 dB (A). A greater variability in Area 1 was noted compared to Area 2 which was attributed to variation in the traffic flow in Area 1 and greater level of continuous background noise in Area 2. It was concluded that both the study areas exceeded the noise limit when compared against WHO guidelines.

Baloye and Palamuleni (2015)measured the noise levels in Ibadan and Ile-Ife city of Nigeria and evaluated the relationship between level of noise and land use pattern 24. Noise levels were measured using android mobile phones equipped with a calibrated noise meter. Measurement was carried out for 10 minutes with 30 sec intervals in A-weighted frequency network. A total of 20 recordings were obtained at a particular location and this was repeated in three time frames namely: morning (07.00-09.00), afternoon (12.00-14.00) and evening (17.00-19.00). The noise measurements were carried out at 20 different locations categorized under commercial, residential, educational and transportation land use type. Results of the study are tabulated in Table. 2.

Table 2: Mean, minimum and maximum level of noise in Ibandan and Ile-Ife regions during morning, afternoon and evening time frame (Baloye & Palamuleni, 2015)[24]

	Level of noise, dB(A)	Ibadan	Ile-Ife
Morning	Mean	74.01	68.59
	Average minimum	68.30	63.45
	Average maximum	78.35	73.4
Afternoon	Mean	72.31	68.91
	Average minimum	65.60	61.9
	Average maximum	77.10	74.9
Evening	Mean	73.23	70.32
	Average minimum	65.15	65.55
	Average maximum	79.55	75.00

The obtained results were also studied to see the relationship between level of noise and the land use pattern (Fig. 2a & Fig. 2b). As seen in Figure, greater level of noise was noted in transportation sector in the city of Ibanda, whereas, in Ile-Ife, commercial land use had greater level of noise. A statistically significant relationship [$F(3, 34) = 15.13$, $p = 0.000$] was noted between land use type and level of noise.

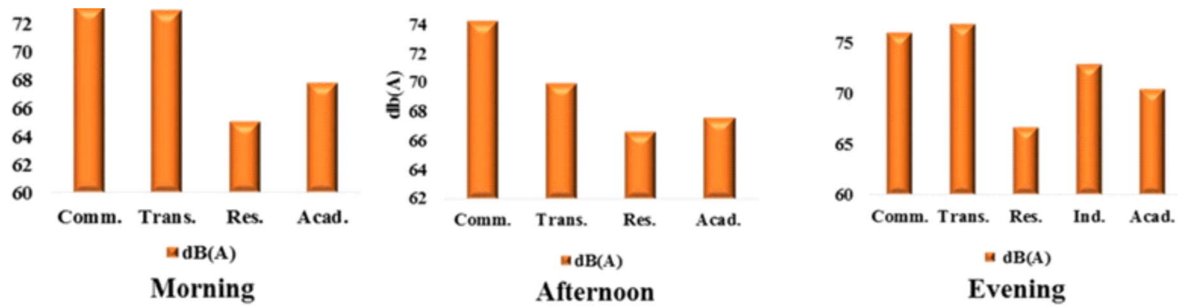

Fig. 2 (a)

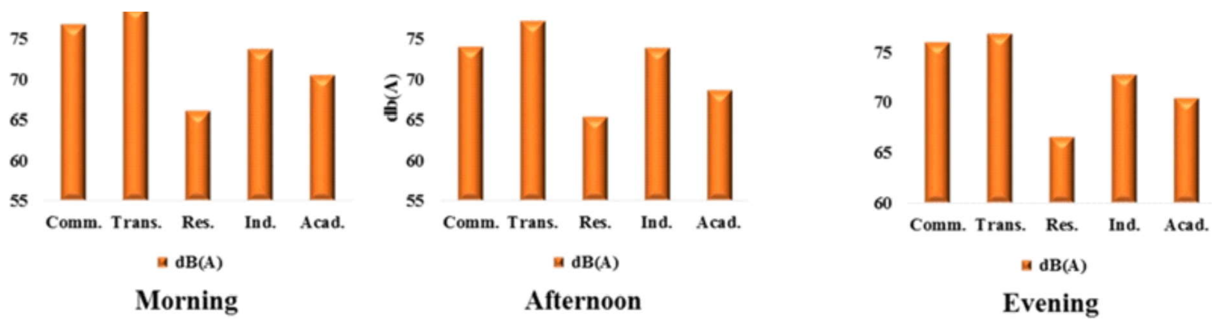

Fig. 2 (b)

Figure 2(a) and Figure 2(b) : Relationship between level of noise and the land use pattern.

Summary of present study indicates that, the level of noise in 79.33% of the measured locations were greater than the prescribed standards and the land use pattern influenced the level of noise in the community.

Similar kind of study was carried out by Akintuyi, Raji, Adewuni and Wunude (2014), where a GIS based assessment and mapping of noise pollution was carried out in Nigeria31. Measurements were carried out at 31 different locations classified under residential, commercial, educational and traffic land use patterns. Noise recordings were carried out during three time frames namely: morning, afternoon and evening. Across all the land uses, lowest daily average of noise ranged between 67.2 dB(A) and 76.7 dB(A). Among the land use patterns, lowest values were recorded in residential areas while higher values were detected in commercial and traffic areas. The computed noise index showed that all the area covered in the study had high index of above 55 dB(A) when compared with WHO standard. Thus, a strict design of noise index was called for, for the safety and sustainable environmental development.

2.2. Noise mapping by calculation procedure

Generation of noise map through calculation procedure calls for a lot of database such as noise emission data, propagation data, reception data and development of geographical model of area under the study. Various specifications have been given such as RLS 90, NMPB, CRTN, etc. for predicting level of noise through calculation procedure. Rather than stopping at the level of prediction, comparison of predicted levels are often carried out with the measured level of noise. This is done for the purpose of validation of the model.

Kalaiselvi and Ramachandraiah (2010) carried out noise mapping study for heterogeneous traffic conditions for the city of Chennai in India[22]. Data was obtained through calculation and measurement procedures. Correlation analysis was carried out among the same for validation. In the calculation method applied, a road traffic noise model was built for three-dimensional digital representation of noise levels associated with emission, propagation and reception of traffic noise. The emission data (vehicle flow rate, percentage of heavy vehicles, *etc.*), propagation data (distance between receiver and source, characteristics of propagation surface, *etc.*) and reception data which included location, height and angle of impact of receiver were built into the model. The area selected was modeled in accordance with the methodology prescribed in RLS 90 specifications. The RLS 90 specifications rate the level of noise at the location of the receiver for day (06.00-22.00) and night (22.00-06.00) time frame to evaluate the impact. Point source method is employed in RLS90 and takes into consideration ground attenuation, screening and reflection. The standard is made up of two separate models namely source model and propagation model. Traffic data is updated in the source model which predicts the reference level of noise at a distance of 25 meters and 4meters above the ground. Average emission for day and night and noise levels calculated in previous phase is considered as an input for propagation model. Noise maps were generated using other specifications such as Calculation of Road Traffic Noise (CRTN), Federal Highway Administration (FHWA) and Statens Planwerk.

For field study and data collection 6 locations were considered for measurement. Norsonic SLM was placed on a tripod at a height of 1.2 meters above the ground level and the measurement was carried out. Measurement duration was for 15 minutes and data was obtained during both working and non-working days. Results of the present study showed a difference of about 10 dB(A) with measured noise being greater than calculated levels. A correlation value (R^2) of 0.847 was obtained. Authors attributed the difference, to the assumption of homogeneity of traffic conditions in the standards prescribed, which is not the case in the city of Chennai. With greater variability in dimensions of vehicles, heterogeneous traffic conditions and lack of lane discipline, honking becomes inevitable leading to greater noise in the environment.

Similar study was carried out by Coelho and Alarcâo (2005)[20], where noise maps were drawn for the city of Almada through on field measurement and simulation procedure. A geographical model of area under study was created and information regarding objects and noise sources in the environment was updated. Emission, propagation and meteorological data were included. Noise maps produced were for two different time periods: day, evening and night. A comparison was made between the level of noise obtained during measurement and that predicted through calculations. Results differed in 2-3 dB for levels obtained through two procedures.

Law, Lee, Lui, Yeung and Lam (2011)outline the development of advanced 3D GIS tools, information technologies and implementation of the same for the purpose of noise mapping in Hong Kong[32]. 2-D noise mapping was inadequate in effectively portraying the noise environment in Hong-Kong due to complex terrain of the city which has close proximity of tall and differently structured buildings and complex road patterns. Hence, the 3D GIS information and computer graphic technologies were employed to present the noise levels at building facades of 3D noise mapping. French GBTT source and 'Calculation of Road Traffic Noise' (CRTN) models were employed for the calculation procedure. A 3-D digital terrain model of Hong-Kong city was developed and necessary source emission and propagation data were updated into the model. 3-D computer graphic technologies were incorporated which would create a virtual environment and allow the viewer to walk or fly through the environment and visualize the level of noise at any user defined locations. The output obtained from the model was compared with the measured values of noise levels for the purpose of verification and results showed that 90% of the predicted data fell within ±3 dB(A) of the measured values indicating a good validity. Application of 3-D information makes it much easier for users to understand the noise environment and master the noise information. Accuracy of the modeling results and the effectiveness in the communication of noise mapping results are enhanced.

Lee et al (2014)estimated the human exposure to road traffic noise at the 25 districts in the metropolitan Seoul, Republic of Korea[25]. Noise levels in the city were modeled using Sound PLAN V.7.1 software. Topographical data and road traffic data were fed into the NMPB model to predict the level of noise. The population exposed to noise was calculated using 3-D façade noise map which estimated the exposed population using average residential area per person. Findings of the present study were compared with major cities in EU. Results indicated that the average percentages of the exposed population exceeding the prescribed daytime and night time standards in Seoul and the EU were 16.6%/34.8% and 13.0%/16.1%, respectively.

Paiva Vianna, Cardoso1 and Rodrigues (2015) conducted a cross sectional study to evaluate the effect of exposure to noise in six urban soundscapes: areas exposed to high and low level of noise in the scenarios of work, leisure and home[33]. The study involved measurement of noise level with generation of noise maps followed by health related enquiries on 180 individuals. 60 individuals assigned to each scenario were divided equally into two groups: one being exposed to high level of traffic noise and the other being exposed to lower levels. The study was conducted in city of Porto. Noise maps were developed to assess the level of exposure to noise in both the areas. Noise maps were based on Lden indicator for work and leisure scenario and home scenario was indicated by Ln (overall level of annoyance). Development of noise map was a three stage process: preparation, modeling and calibration. In the preparation stage, identification of noise source, measurement and counting. The soundscape modeling was carried out with the help of Cadna-A software and Lden and Ln were computed as per calculations prescribed in Road traffic noise prediction (NMPBRoutes-96). Validation of the predicted levels by the software was carried out in calibration stage by comparing with the measured levels of noise in the area. Measurements were carried out with the help of calibrated SLM placed at height of 1.20 meters from the ground level. Noise was recorded for 20 minutes in each of the three periods: morning, evening and night. The difference between Leq measured and obtained was less than 4.6 dB.

In the further part of the study, evaluation of perception of noise source and the annoyance was carried out in all three scenarios. Results showed that, in the scenario of leisure time 65% of interviewees mentioned perception of noise source among which 20% reported of little annoyance. No statistically significant association between exposure to noise, perception of noise and annoyance. Noticing of noise source in work environment was reported by 85% of the interviewees out of which 48.3% reported of annoyance. Statistically significant association was noted between exposure and perception of noise source (p=0.01) and also for annoyance due to noise source (p=0.07). Among the interviewees 60% reported noticing of noise source among which 56.7% reported of annoyance. Statistically significant association was noted between exposure and considering home a noisy location and also for annoyance due to noise source. Authors concluded that, the study carried out enlightens the information on relationship of urban noise with non-auditory health effects and factors that are associated with annoyance, by assessing the exposure to urban noise in different scenarios.

Although both procedures (calculation and onsite measurement) have been employed in the process of noise mapping, each has its own pros and cons. Maps drawn from measurement, lead to a static map with overall values, where identification of noise source is often difficult. Whereas, that from calculation methods are more dynamic, allowing for easy updates and contribution of each noise source can be distinguished 20. The noise levels are accurate in direct measurement, but there would be difficulties in selecting various measurement sites to estimate the exposed population in citywide noise mapping 25. A difference of up to 10dB (A) could be seen between measured and calculated noise levels[22]. However, generation of noise maps through calculation methods demands several calculations, data input, which is accurate and large in number, substantial computer power and memory, which is not the case for onsite measurement. Although noise maps based on measurement procedure have been commonly used in the past, calculation methods are now being adopted widely for generation of noise maps due to advancement in computer technology and its application.

3. DISCUSSION

From there view of the above literature, it is evident that both the methods of noise mapping have been employed in the studies, with a lot of dynamicity added into the approach. One can choose among the procedure for employment depending on the availability of resources and purpose of noise mapping. With respect to the above view, drawing an ideal framework for the purpose of noise mapping is attempted in the following section.

3.1 Selection of procedure

Although both the procedures have been employed in the literature for the purpose of noise mapping, selection of one depends on various factors. For the application of calculation procedure, one needs to possess large and accurate data regarding source, propagation and reception. For this purpose, one should know information on number of vehicles, percentage of heavy vehicles per hour, vehicle speed, type of traffic, etc. If sufficient data are not available, one needs to do traffic counting manually. Although good traffic data is available, it is applicable only during day time (06.00-22.00) as one would not be interested in monitoring traffic at night. Hence, one has to obtain night traffic data manually[34]. Along with this, computer power and memory on large scale is called for. Measured level of noise 10 dB(A) higher than the calculated levels (RLS 90 specification) was reported by Kalaiselvi and Rama chandraiah (2012)[22] in city of Chennai which was attributed to heterogeneous traffic conditions and poor lane discipline which is often the case in developing countries. Assumption of homogeneous traffic conditions lead to this draw back. Hence, method of measurement of noise at the site is preferred as the levels measured here are more accurate[25]. However, information on source of noise should be given along with the data, and application of mapping software such as GIS allows for easy update of measured values is needed. Combination of both the approaches would be ideal where, measured and predicted level of noises could validate one another[20,22]. However, selection of this option would depend on the availability of valid resources.

3.2. Allocation of site of measurement

Measurement locations could be placed equidistantly from one another or at varying distances depending on the population density. It depends on the purpose of the study, as whether an entire city is being mapped or just a portion of it. Equidistant allocation of measurement locations could be done using mapping software. However, one needs to take a decision as to whether to equidistantly allocate locations or assign them depending on the thickness of the population. On noise mapping of an entire city, measurement of noise levels in densely populated and more active regions should be carried out at greater number of locations as these regions are subjected to substantial variations in level of noise (due to several factors such as amount of traffic flow, level of activities going on, etc.) compared to regions that are less populated. Similar approach has been used byIaaly-Sankari *et al.* (2010)[23], where 350 measurement points were allocated with the distance among the measuring points varying from 50-150 depending on the density of the population.

3.3 Time frame of noise measurement

An ideal noise measurement should encompass level of noise spanning all the 24 hours from day to night and allocating them under different time frames namely: morning, afternoon, evening and night. King *et al.* (2012) have measured the level of noise across the 24 hour time span in residential and residential-commercial mixed land use pattern[30]. However, most of the studies in the literature[24,28,29] have not included a 24 hour timeframe due to practical and feasibility factors. Hence, the time frame for noise measurement should be such that, the data obtained is a good representative of the noise profile of area under the study.

3.4 Measurement procedure and settings

Several national and international standards (ISO standards, OSHA guidelines, *etc.*) are available regarding measurement of environmental noise levels. These standards could be adopted for the measurement procedure, with any modifications if necessary and aptly justified. Preferably SLM should be placed at a height of 1.2-1.5 meters from the ground level so that it is at the level of receptor[22,28,30,35]. The frequency weighting and time weighting depends on the type of noise measured. A-weighting is most commonly used in environmental noise measurement which is sensitive for mid-high range of frequencies. The 'A' weighting frequency network in 'Fast' range simulates human Ear listening response and is generally used for environmental noise measurement 28. Peak measurements and low frequency noise can be measured using C-weighting network. It is often used in entertainment noise measurement, where high pressure low frequency noise is common. Z-weighting is a flat frequency response of 0.5 Hz to 20 kHz ±1.5dB, which has been used to measure explosive sounds and in the assessment of low frequency noise[35]. 'Impulse' mode time weighting is generally used for measurement of impulsive noise such as cracker burst, gun firing, *etc*. The noise subjected to investigation should be measured for sufficient duration such that the measured value represents the actual scenario. Duration of measurement should be at least of 15 minutes unless the given noise is not present for such duration[35]. However, various measurement durations have been adopted in the literature ranging from 10 minutes to eight hours[22,23,24,30]. Temperature gradient in the atmosphere can drastically effect the sound propagation. Temperature at the ground increases during sunshine and as a result the air will be warmer at the ground level compared to higher amplitude which causes sound waves to refract upward, away from the ground. As a result lower noise levels are being heard at the listener's position. The reverse happens in the evening time resulting in cooler temperatures near the ground causing sound to bend downward toward the ground resulting in louder noise levels at the listener position. Wind and temperature gradients can influence sound propagation over long distances and further complicate measurements[36]. All the measurements should be carried out under suitable weather conditions, where wind speed will be < 5 meters/sec with no rain 35 and humidity and temperature being ideal (15-25°c & 70% respectively) as barring this criteria would affect the accuracy of measurement[27].

3.5 Analysis of the obtained data

The data obtained through noise mapping could be analyzed in various ways depending on the aim of the study. The obtained data could be analyzed to see the relationship between noise levels and land use pattern[24,28,30], time of measurement and level of noise[24], site of measurement and level of noise[29] and in many other possible ways. Analyzing the data based on the land use pattern helps the concerned authority to decide whether area under study is suitable for the land use pattern assigned, by comparing it with the prescribed standards for maximum permissible levels and to bring any necessary modification in the land use pattern. Studying the relationship among level of noise and time of measurement would help to identify source or events which exceed the permissible noise levels, such as increased levels of noise in traffic peak hours, evening recreational activities, *etc.* and formulate necessary actions to monitor the issue. Hence, appropriate analysis could be used based on the need.

3.6 Computation and display of the results

The obtained data could be computed in many different ways depending on the purpose of the study. LAeq, Lden, Lmax, Lmin,Lpeak, Ln and LRden are the commonly used noise indices in the literature[24,28,29,30]. Display of results in an effective way would be an important aspect as it gives a clear picture regarding the noise scenario. Obtained results could be displayed in several ways depending again on the purpose of study and way of data analysis. Although bar graphs[22], pie chart[24] and line graphs[30] are employed in the literature to display the results, the purpose of noise mapping would be incomplete without the representation of results on a noise map. An Isopleth noise map would be an ideal choice for representation as it shows spatial distribution of noise levels in the environment. Standard color coding as prescribed[37] could be used to represent the level of noise and how it varies across the areas. A 5 dB noise bands could be used to represent the noise levels from 30 dB to levels greater than 80 dB. Based on a color coded noise map, one would be able to identify the level of noise in any area under the study and at any particular time. This would be handy for any concerned authority to bring necessary actions in order to keep the noise levels in check.

4. CONCLUSION

Noise pollution in recent years has been considered as one of the serious threats for physical well-being and mental peace of an individual. With rapid growth and advancement in globalization, there is drastic change in urban soundscape, calling for an immediate action for noise management. With noise mapping being an ideal tool to monitor environmental noise levels, various noise mapping studies have been carried out using different methods. Although, the procedures can be classified as calculation procedure, onsite measurement or combined method, there is a lot of variability in the approaches used. Hence, the current article attempted to draw an ideal frame work for the process of noise mapping based on available articles published in the literature. However, one should be flexible enough to adopt any change in the process depending on the need of the study and provide justification for the same. It should be noted that, the process of noise mapping does not end with the generation of noise maps. The application of the information obtained in the map, shall be made by the policy makers to identify the sources of noise, areas exceeding prescribed noise limits, the population affected by the same and adopt certain action plans to reduce the effect of noise on human health and to maintain a healthy environment. As this concept is very new to India, there are limited studies in this domain. Also, the noise levels are comparatively higher in loudness in India and may vary from different regions, wider scales studies are required to address this concern.

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A survey regarding knowledge about Noise Polution Acts of India in Urban and Rural Population

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ABSTRACT

In today's world there are various sources of noise which are directly or indirectly affecting on the human health. And due to various types of noises the general population feel helpless to control these sources. To control these hazardous effects of noise Since 1970 the Government of India has developed various laws/acts and rules. The aim of this study is to check whether the general public in urban and rural areas are aware about these acts or not and in which areas there is a need to create awareness. To check the awareness between urban and rural areas a questionnaire has been developed which has included questions regarding various acts of noise control and administered on urban and rural population. The result of the study has showed that, awareness among rural population is less in comparison to urban population and the results were significantly different.

1. INTRODUCTION

A sound, especially one that is loud or unpleasant or that causes disturbance is known as noise. The common sources of noise include the noise generated from industrial areas, traffic, fighting for parking plots, social events such as Ganesh Chaturthi festival, Diwali, Dusshehra, marriage function, rally, party club, etc. There are various effects of noise on human health and wellbeing such as hearing problem, health issues, sleeping disorders, cardiovascular issues, trouble communicating, *etc.* The World Health Organization (WHO) recognized noise as one of the major pollutants affecting the health of the human population[1]. To prevent the population from these hazardous effects of noise, the government since 1970s is showing concern for providing noiseless environment through various environmental acts and policies in India. There are multiple laws in India for controlling environmental pollution. There are some laws that directly deal with the issues of noise pollution such as Noise Pollution Control under the Indian Penal Code (1860) in which Noise is considered as public nuisance under Section 268 of the Indian Penal Code and thus, there is a criminal liability of a person relating to his illegal omission resulting in common injury, danger or annoyance to the people in general, Noise Control under Railway Act (1890), Aircraft Act (1934), Noise Pollution Control under the Code of Criminal Procedure (1973), Air (Prevention and Control of Pollution) Act (1981), The Environment (Protection) Act (1986) under sec. 6 has mentioned "Rules To

Regulate Environmental Pollution", This section has explained the maximum allowable limits of concentrations of various environmental pollutants (including noise) for different areas and the Environment (Protection) Rules (1986).

Even though there are various laws to control noise pollution, the actual awareness about all these acts is lacking among general population. The acts will actually serve their purpose if they are efficiently used to control noise pollution. There are no studies which have attempted to evaluate the awareness/ knowledge about the noise pollution acts among general population in India. Thus, there is need to evaluate the knowledge which would guide further evaluate the efficacy of these laws. The present study attempts to evaluate the knowledge about noise pollution acts in both urban and rural population. The present study aims to assess the knowledge of noise pollution acts in general population. The objectives were to assess the awareness of noise acts in general population and to compare the awareness of noise acts in rural and urban population.

2. METHOD

A questionnaire was designed in English considering the different Noise pollution acts by Government of India for controlling the noise effects. The Questionnaire included questions regarding Noise pollution acts which included Pollution Control under the Indian Penal Code (1860), The Noise Control under Railway Act (1890), Aircraft Act (1934), Noise Pollution Control under the Code of Criminal Procedure (1973), Air (Prevention and Control of Pollution) Act (1981), The Environment (Protection) Act (1986) and the Environment (Protection) Rules (1986).

The questionnaire was administered on urban as well as on rural population. The survey included questions which were simple to comprehend (Ex. Are you aware that there are noise pollution acts to control noise pollution, etc). The survey questions were made by the study authors who are certified audiologists. Initial drafts of questionnaire was reviewed and validated by 10 researchers and clinical audiologists with an experience of at least 5 years in this field. They evaluated in terms of appropriateness, importance and correctness of the questions. The suggestions provided by them were incorporated and the final questionnaire was completed. The questionnaire is provided in Appendix 1.

2.1 Participants

A total of 200 individuals participated in the study. Questions were administered on 100 individuals from urban area and 100 individuals from rural area. The questionnaire was administered on individuals who are literate (With minimum X standard). The mean age of participants was 30.67 years with standard deviation of 5.38.

The survey questions addressed different noise acts by Government of India to assess the knowledge about these noise acts which includes information regarding maximum amount of permissible noise levels in different zones (residential zone, industrial zone, *etc.*), maximum allowable time for industrial workers who are exposed to various noise levels, punishment for violating noise laws and effects of noise on hearing sensitivity, as well as rights to take actions against noise pollution, *etc*.

2.2 Informed Consent

An informed consent was taken from all the participants and confidentiality from all the participants was maintained. The questionnaire took nearly 10 minutes to complete. And questions were read by the researcher and their responses were noted.

2.3 Data Analysis

The correct responses, the incorrect responses and response 'Don't know' was scored and tabulated for both urban and rural population.

3. RESULTS

The results of the study showed that the correct responses were more in urban population compared to rural population. The results of the same are shown in figure 1. On the X-axis different areas are given and Y-axis indicates percentage scores of the correct, the incorrect, and don't know responses. The results of the study has showed that among urban population, 55.3% of them answered correctly, 26.92% of them gave incorrect response and 17.78% of them were not aware of the noise laws. And among rural population, only 32% of them answered correctly, 30% of them gave incorrect response and 38% of them were not aware of the acts.

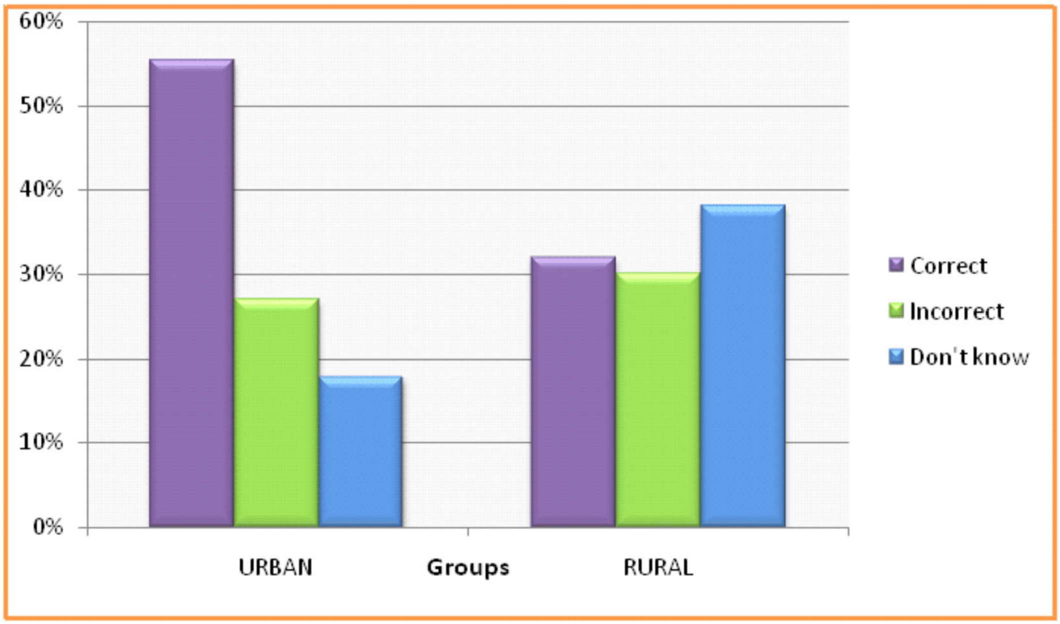

Fig. 1. Percentage scores of the correct, the incorrect and Don't know responses in urban and rural population

The average number of correct, incorrect and don't know responses for individual questions of the questionnaire are provided in Table 1. The values showed that questions related to awareness of noise pollution control acts and effects of environmental and residential noise on hearing have scored higher that is greater 80% in urban area, whereas in rural area these questions have scored 50%. In urban population, questions which includes knowledge about maximum levels of noise which cross the quality standards as prescribed by the government as well as obtaining permission before using the loud speakers, the allowable timings to use the loud speaker and question related to sources of noise have scored above 75% but less than 80%. And 50% of rural population are aware about this knowledge. 50% urban and less than 50% rural population knew the punishment for violating these laws. Half of urban population are aware of right to call police if there is noise pollution and punishment penalty if laws are broken for noise pollution. Information about existence of neighbour law and maximum permissible noise level during day and night time for industrial area is known only to 50% of the urban population and less than 30% of rural public. It has also been observed that percentage score are less than 30% in both urban and rural population for questions regarding maximum permissible levels in residential areas and level of impulse noise produced by firecrackers. Tremendously low score is seen for the question which was asked about the total time of exposure per day when exposed to noise of 90 dB (A) for which only 14% urban and 5% of rural population has answered correctly.

Table 1: Average response for individual questions in urban and rural population

Question no.	Urban population			Rural population		
	Correct	Incorrect	Don't know	Correct	Incorrect	Don't know
1	80	13	7	50	29	21
2	78	14	8	51	20	29
3	75	19	6	50	24	26
4	79	16	5	51	27	22
5	61	22	17	37	26	37
6	79	13	8	43	32	25
7	83	16	1	48	30	22
8	55	28	17	30	45	25
9	57	31	12	25	36	39
10	43	14	43	20	42	38
11	21	49	30	13	17	70
12	33	36	31	15	25	60
13	16	67	17	10	29	61
14	14	39	47	5	38	57
Average %	**55.3**	**26.92**	**17.78**	**32**	**30**	**38**

Inferential statistics were done to determine if there is any significant association between the correct and incorrect responses between the groups. Chi square test was administered for the same. The result of chi-square test shows that the correct responses were significantly higher for urban population compared to rural population. The chi-square statistics is $\chi 2 = 13.3812$, $p<0.05$. In addition, it was also found that the number of incorrect responses were also significantly lower in urban population compared to rural population.

4. DISCUSSION

The result of the study shows that the general population is not aware of most of the noise laws and rules and regulations laid by Government of India to control noise pollution. The awareness was significantly poor especially in rural population compared to urban population. From the study, it was found that about 83% people from urban area and 48% of people from rural area reported that the noise can affect hearing sensitivity. Questions pertaining to awareness of noise pollution control acts scored high *i.e.* 80% by urban population and 50% by rural population which suggest that there is a dire need to create awareness among the rural public about different types of noise acts. From the questionnaire, it is observed that there is very little awareness regarding different levels of maximum permissible noise permitted in different zones (residential zones, industrial zones, *etc.*) and for various situations (day time, night time). So it is very important to make the people more knowledgeable about these permissible noise levels. There is lack of awareness in terms of punishment or penalty if laws are violated. Due to this lack of knowledge, the general public is helpless in front of these noise polluters.

In general, only around 55% of urban population and around 32% of rural population answered correctly. This suggests that there is an urgent need to create awareness among the general public regarding the noise laws and steps taken to control noise pollution in India. The curriculum of school students can also stress more on creating awareness about the noise laws and harmful effects of noise pollution. The focus should be more on rural population who require more awareness programs. Nationwide awareness camps, seminars, advertisement in television, radio, and social media about these facilities would further enhance the awareness.

Appendix 1

Checklist for awareness of rules and regulations for Noise pollution

Sl. No	Questions	Yes	No	Don't Know
1	Are you aware that there are noise pollution control acts to control noise pollution?			
2	Do you think it is okay if the levels of noise cross the quality standards as prescribed by the government?			
3	Loud speakers can be used without obtaining a permission in written from authorities?			
4	Do you think that loud speakers can be used before 6 am and after 10 pm?			
5	Person violating the laws or provisions or causing noise in a particular area is not liable for getting punished?			
6	Do you think in addition to factories, trains and airplanes, religious and social ceremonies are noise nuisance?			
7	Do you think environment (Eg.Transportation, air-crafts, trains, road vehicles) and residential noise can affect your hearing?			
8	You do not have the right to call police if there's noise pollution.			
9	There is no punishment/penalty if laws are broken for noise pollution?			
10	There exists a neighbor noise law? (nuisance form neighbor)			
11	Do you think that 50dB HL (Eg. Quiet suburb, conversation at home, large electrical transformers at 100 feet) is the maximum permissible noise level during day time in residential area?			
12	Do you think 100dBHL (Eg. Motorcycle, Farm tractor, etc.) is the maximum permissible noise level during night time for industrial area?			
13	Do you agree that manufacture and sale of crackers having an impulse noise of 70 dB (A) (Eg.Conversation in restaurant, office, etc.) at 5meters distance from the site of bursting should be banned?			
14	Do you think that 10 hours is the total time of exposure per day when exposed to noise of 90 dB(A) (Eg. power mower)?			

5. CONCLUSIONS

The present study attempted to evaluate the knowledge among the general public regarding the noise laws. The results of the study showed that most of the general public are not aware of the noise laws and rules and regulations to control noise pollution. The awareness was poor especially among rural population compared to urban population. Thus, the study suggests that there is an urgent need for more awareness among general public regarding the noise laws. This would also help in effective control of noise pollution.

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Theory of the tuned side-inlet axial-outlet muffler*

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ABSTRACT

An efficient exhaust muffler is designed as wide-band low-pass acoustic filter. As implied in the logarithmic addition, the low-frequency zero-dB troughs would result in drastic reduction in the overall insertion loss (IL) of the muffler. Therefore, during the last decade, tuned extended inlet/outlet chambers have been developed, where lengths of extended inlet/outlet are designed so as to tune out or cancel the troughs of the simple expansion chamber (SEC) muffler. In the present paper, an analytical expression has been derived for the TL curve of a tuned side-inlet axial-outlet (SIAO) muffler by means of electroacoustic analogies and transfer matrix method. This expression explains why the base TL curve of the tuned chamber is similar to that of the corresponding SEC with effective length reduced to half and area ratio increased to double. Consequently, one dome of the tuned chamber spans over two domes of the SEC-TL curve, and stands 6 dB higher than the TL-domes of the corresponding SEC.

1. INTRODUCTION

Nearly a century ago, use of electroacoustic analogies, with acoustic pressure and particle velocity corresponding to electrical voltage and current respectively, led to the development of a simple expansion chamber (SEC) muffler (see Fig. 1) as a low-pass one-dimensional acoustic filter for use on the exhaust system of the then newly developed internal combustion engine. Making use of the plane-wave theory and assuming inviscid stationary medium, transmission loss (TL) of the muffler of Fig. 1 is given by[1].

$$\text{TL} = 10 \log \left\{ 1 + \frac{1}{4}\left(m - \frac{1}{m}\right)^2 \sin^2 (k_o l) \right\} \text{(dB)} \tag{1}$$

where $m = A_2/A_1 = A_2/A_3 = (D/d)^2$ is the area expansion ratio of the muffler (see Fig. 1),

$k_0 = \omega/c_0$ is the wave number,

$\omega = 2\pi f$ is the radian frequency, corresponding to frequency f in Hertz, and

$k_0 l$ is generally called non-dimensional frequency or Helmholtz number.

* A preliminary version of this paper was presented at WESPAC 2018, New Delhi, India, November 11-15, 2018.

The TL plot of Fig. 1, shown in Fig. 2, is characterized by periodic domes which make the SEC of Fig. 1 unsuitable for attenuation of exhaust noise of a variable speed automotive engine. The arithmetic of logarithmic addition indicates that any troughs at low frequencies would drastically reduce the overall insertion loss of the muffler at some engine speed[1]. Therefore, wide-band TL curve is necessary.

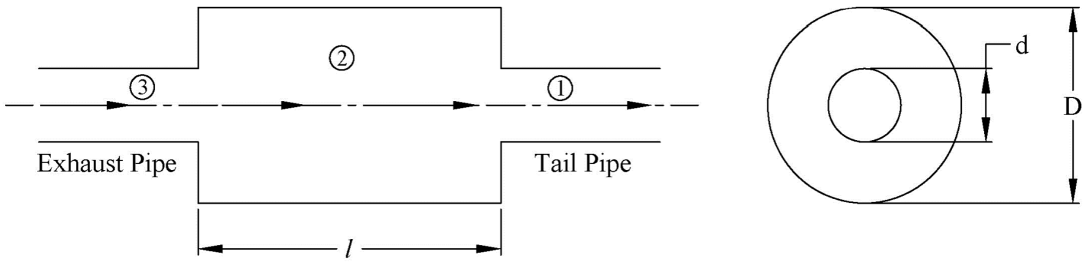

Fig. 1. Schematic of a simple expansion chamber (SEC) muffler.

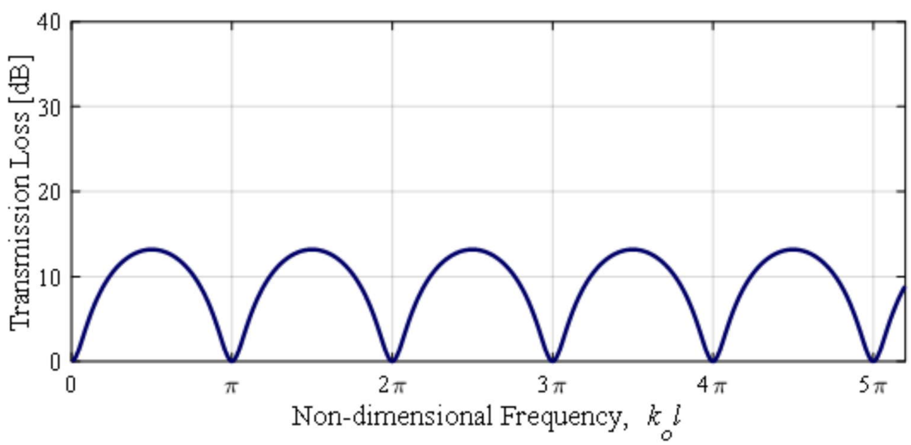

Fig. 2. TL of the simple expansion chamber (SEC) muffler of Fig. 1 for m = 9.

One way to raise a TL trough is to extend the inlet pipe or outlet pipe into the chamber so that the lowest resonance frequency of the quarter-wave resonator coincides with that of the trough ($k_0 l = \pi$)[2].

This extended inlet (or outlet) chamber muffler would tune out all odd-numbered ($2n - 1$, n = 1, 2, 3) troughs. Similarly an extension of length $l/4$ would cancel or raise the even numbered ($2n$, n = 1, 2, 3, ...) troughs in the TL spectrum[3]. But then, one must take into account the end corrections by reducing the physical lengths of the extended inlet/outlet accordingly[3, 4]. This end-correction would not be applicable for the side-inlet axial outlet (SIAO) muffler shown in Fig. 3, where the direction of plane waves in the chamber would still be axial as indicated in the figure[5, 6]. Incidentally, the SIAO muffler is a logistic necessity for the diesel generator sets, where the exhaust muffler sits on the top of the canopy or acoustic enclosure.

All these papers[2-5], however, donot explain how cancelling the troughs by means of sharp peaks of quarter-wave resonators would raise the entire curve around the peak into a single raised dome. This is addressed in the present paper by deriving a closed-form expression for the TL spectrum for the muffler of Fig. 3 and arranging it in a form similar to Eq. (1). In the process, it is shown that the SIAO muffler of Fig. 3 behaves like the SEC muffler of Fig. 1 with length l reduced to $l/2$ and area ratio increased from m to $2m$. This has some interesting design implications.

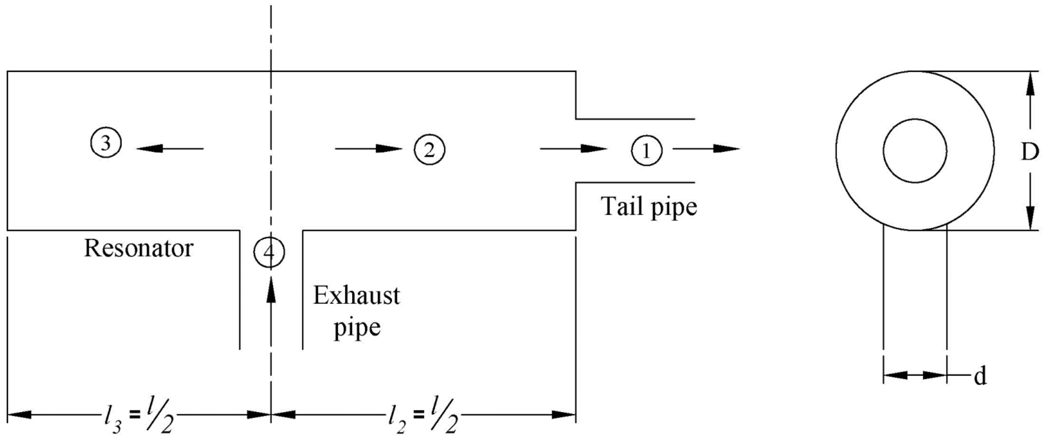

Fig. 3. Schematic of the side-inlet axial-outlet (SIAO) muffler.

2. PLANE-WAVE ANALYSIS OF THE SIAO MUFFLER OF FIGURE 3

When the incoming waves in the exhaust pipe (element No. 4) enter the SIAO muffler shown in Fig. 3, they encounter a quarter-wave resonator of length l_3. Then they move along the intermediate portion of length l_2 towards the tail pipe.

An equivalent Electro-Acoustic analogy circuit for the muffler of Fig. 3 can be formed by using distributed elements and shunt lumped elements[1] as shown in Fig. 4.

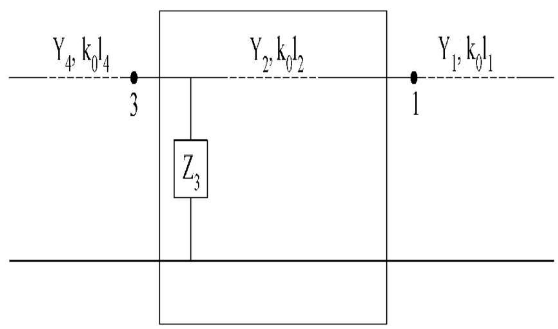

Fig. 4. The equivalent electroacoustic analogy circuit.

The transfer matrix for the boxed circuit of Fig. 4, which relates the upstream variables (at pt. 3) to those of downstream (at pt. 1), can be written as[1]:

$$\begin{bmatrix} p_3 \\ v_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{1}{Z_3} & 1 \end{bmatrix} \begin{bmatrix} \cos k_0 l_2 & jY_2 \sin k_0 l_2 \\ \frac{j}{Y_2} \sin k_0 l_2 & \cos k_0 l_2 \end{bmatrix} \begin{bmatrix} p_1 \\ v_1 \end{bmatrix} \tag{2}$$

where Y_2 is the characteristic impedance, c_0/A_2, of the pipe element 2, p_i is acoustic pressure variable and v_i is the mass velocity variable, at point i, i = 1, 3.

We can tune the side-inlet side-outlet muffler by taking lengths $l_3 = l_2 = 1/2$, as shown in Fig. 3. For convenience of typing, let us say

$$\cos k_0 l_2 = \cos k_0 l_3 = \cos k_0 l/2 \equiv \text{C}, \ \sin k_0 l_2 = \sin k_0 l_3 = \sin k_0 l/2 \equiv \text{S}. \tag{3}$$

Multiplying out the matrices of Eq. (2) yields

$$\begin{bmatrix} p_3 \\ v_3 \end{bmatrix} = \begin{bmatrix} C & jY_2 S \\ \dfrac{C}{Z_3} + \dfrac{j}{Y_2} S & \dfrac{jY_2}{Z_3} S + C \end{bmatrix} \begin{bmatrix} p_1 \\ v_1 \end{bmatrix} \tag{4}$$

where,

$$Z_3 = -jY_3 \cot(k_0 l_3) = -jY_3 C/S \tag{5}$$

is the equivalent impedance of the resonator cavity 3, at the exhaust pipe junction[1].

Assuming the area of exhaust pipe diameter to be equal to that of tail pipe, we get

$$A_4 = A_1 \Rightarrow Y_4 = Y_1$$

where A and $Y = c_0/A$ denote the cross-sectional area and characteristic impedance, respectively.

Let us define the area expansion ratio m as:

$$\frac{A_3}{A_1} = \frac{A_2}{A_1} = m, \ (m = D/d)^2 >> 1) \tag{6}$$

Then,

$$\frac{Y_4}{Y_1} = \frac{A_1}{A_4} = 1, \ \frac{Y_3}{Y_1} = \frac{Y_2}{Y_1} = \frac{1}{m} \tag{7}$$

Transmission loss, in terms of the overall four-pole parameters, is given by[1]

$$TL = 20 \log \left[\left(\frac{Y_1}{Y_4} \right)^{\frac{1}{2}} \left| \frac{T_{11} + T_{12}/Y_1 + Y_4 T_{21} + (Y_4/Y_1) T_{22}}{2} \right| \right] \tag{8}$$

where the four-pole parameters T_{11}, T_{12}, T_{21} and T_{22} refer to the product transfer matrix of Eq. (4).

Making use of Eqs. (3) to (7), different terms in Eq. (8) can be written as

$$\frac{Y_1}{Y_4} = 1 \tag{9}$$

$$T_{11} = C \tag{10}$$

$$\frac{T_{12}}{Y_1} = \frac{jY_2 S}{Y_1} = \frac{jS}{m} \tag{11}$$

$$Y_4 T_{21} = \frac{Y_4}{Z_3} C + \frac{jY_4}{Y_2} S = \frac{Y_4}{-jY_3 C/S} C + \frac{jY_4}{Y_2} S = 2jmS \tag{12}$$

$$\frac{Y_4}{Y_1} T_{22} = \frac{jY_2 S}{Z_3} + C = \frac{jY_2 S}{-jY_3 C/S} + C = -\frac{S^2}{C} + C \tag{13}$$

Substituting Eqs. (9) to (13) in Eq. (8) and rearranging, we get

$$TL = 20 \log \left\{ \frac{\left| C + \dfrac{j}{m} S + 2jmS - \dfrac{S^2}{C} + C \right|}{2} \right\}$$

$$= 20 \log \left\{ \frac{\left| 2C - \frac{S^2}{C} + jS\left(\frac{1}{m} + 2m \right) \right|}{2} \right\}$$

$$= 10 \log \left\{ \frac{\left(2C - \frac{S^2}{C} \right)^2 + S^2 \left(\frac{1}{m} + 2m \right)^2}{4} \right\}$$

$$= 10 \log \left\{ C^2 + \frac{S^4}{4C^2} - S^2 + \frac{S^2}{4} \left(4m^2 + \frac{1}{m^2} + 4 \right) \right\} \tag{14}$$

Further simplifying the above equation, the transmission loss for the Side-Inlet Axial-Outlet (SISO) muffler of Fig. 3 is given by

$$TL = 10 \log \left\{ 1 + \frac{1}{4} \left(2m - \frac{1}{m} \right)^2 S^2 + \frac{S^4}{4C^2} \right\} \tag{15}$$

where it may be recalled,

$$S \equiv \sin (k_0 l/2) \text{ and } C \equiv \cos (k_0 l/2) \tag{16}$$

Thus, TL of the SIAO muffler of Fig. 3 can be written out as

$$TL = 10 \log \left\{ 1 + \frac{1}{4} \left(2m - \frac{1}{m} \right)^2 \sin^2 \left(\frac{k_0 l}{2} \right) + \frac{\sin^4 (k_0 l/2)}{4 cos^2 (k_0 l/2)} \right\} \tag{17}$$

3. RESULTS AND DISCUSSION

Typically, m is of the order of 10 and therefore $1/m$ would be negligible with respect to m or $2m$. Dropping this term in Eqs. (1) and (17) we can observe that

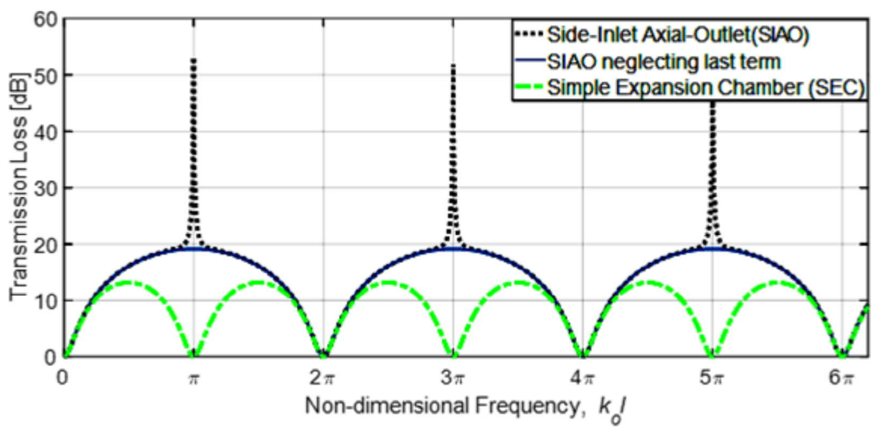

Fig. 5. Comparison of the TL of the SIAO muffler of Fig. 3 with that of the SEC muffler of Fig. 1.

(i) The SIAO muffler of Fig. 3 behaves like the SEC of Fig. 1 with half the length ($l/2$) and double the area ratio ($2m$).

(ii) The last term ($S^4/4C^2$) in Eq. (17) is responsible for producing sharp peaks at the non-dimensional frequency $k_0 l = \pi, 3\pi, 5\pi$.... on the Transmission Loss curve, as shown in Fig. 5.

For the control of exhaust noise of a variable-speed reciprocating internal combustion (RIC) engine, sharp peaks in Fig. 5 are of no use. Therefore, neglecting the last term in Eq. (17), leads to the full-line curve in Fig. 5. Comparing this curve with the SEC curve in Fig. 5 indicates that

(a) The first two domes of the SEC muffler TL get replaced by a single dome that stands higher by

$$20 \log \left(\frac{2m}{m}\right) = 6dB.$$

(b) This feature is repeated for the subsequent pairs of the SEC-TL domes.

4. CONCLUSION

For typical automotive engines, the unmuffled exhaust sound pressure level (SPL) peaks at the engine firing frequency, and its first couple of harmonics. At these rather low frequencies, Helmholtz number $k_0 l$ would generally fall below 2π, and therefore feature (a) of the SIAO muffler of Fig. 3 would increase the overall insertion loss of the muffler considerably[1, 7].

The analytical approach presented here has been extended recently to the double-tuned side-inlet side-outlet mufflers[6].

5. ACKNOWLEDGEMENTS

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Propeller noise control by varying the thickness of blade

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ABSTRACT

Machinery, flow and propeller are the three sources of underwater radiated noise of marine vehicles. While machinery noise control methods are well established, propeller and flow noise control approaches are not so well established. This paper brings out a study carried out on propeller noise. The main aim of present work is to control propeller noise by changing its geometry through varying its blade thickness. Numerical simulation using CFD and Acoustic analysis was employed for this study. Large-eddy simulation (LES) in CFD analysis and Ffowcs Williams Hawkings (FW-H) equation in acoustic analysis were used for predicting unsteady non-cavitating noise of marine propeller. Study was carried out on propeller of chosen geometry with 5 and 6 blades by increasing the thickness of existing propeller by 0.1mm to 0.5mm at specified operating conditions. From the results it is observed that the 6 bladed propeller with increase in blade thickness of 0.5mm generates lesser noise compared to other propeller configurations studied. It is also shown that this low noise propeller meets the hydrodynamic performance requirement.

1. INTRODUCTION

Radiated noise of a marine vehicle is a major vulnerability in defense warfare. This noise emanating from the vehicle consists of contributions from machinery, propeller and flow. Since machinery noise is of interest in many other sectors such as industries, a lot of progress was achieved for its control. However, propeller and flow noise is of limited interest as these are important primarily for defense vehicles such as combat aircrafts and ships. Thus, relatively limited work is reported on these topics. From literature review, it is seen that very few studies were carried out on marine propeller's noise and its control. Thus, there is a huge scope for study of marine propeller noise and its control.

A propeller consisting of its hub and blades mounted on an engine driven rotating shaft creates a relative motion by forcing the fluid axially backwards. The radiated noise from the propeller depends on its geometry, wake inflow and propeller isolation. Geometrical modification of a propeller can be implemented by varying parameters that influence the noise levels. These parameters are number of blades, pitch angle, blade area, blade diameter, skew angle, trailing edge geometry and blade finishing fineness.

This paper presents a study carried out on propeller noise control by varying blade thickness of propeller. In this study, prediction of non-cavitation noise of propeller for five and six bladed propellers with blade thickness increments was carried out by employing CFD analysis followed by acoustic analysis. From the studies, propeller configuration resulting in low noise was arrived at among the studied configurations. Apart from this, the study brought out that hydrodynamic performance of this low noise propeller meets the functional requirement implying that the configuration arrived is suitable for implementation.

2. LITERATURE REVIEW

Propeller/fan noise and its control were studied by several researchers in the past. Some of these studies showed that propeller/fan noise can be controlled using geometrical modifications. It is seen from this literature that most of the studies focused on aero applications and axial fans.

Kuznetsov[1] identified various noise sources from different types of passenger airplanes. Various methods for reduction of noise from both inside and outside an airplane were discussed. He determined the method of increasing the efficiency of noise-suppressing systems used in power plants and applied it on reducing the intensity of airplane noise sources. Mohammad *et al.*[2] studied various methods of noise reduction for marine propeller. He brought out that various methods can be used for reducing propeller noise like modification of inlet flow, changing the propeller geometry and the confinement of the propeller. He studied the effects of trailing edge noise from the propeller.

Cleon and Willaime[3] explained methods used to reduce noise level from an axial flow fan. Optimization of the shape of the blades, their number and their twist law contributing to the performance and reduction of acoustic emission has been achieved. Nemec[4] conducted theoretical and experimental investigations for reducing the siren noise radiated from the compressors and axial fans by changing the blade design. Theoretical analysis on the effect of beveling on the noise levels of the fans was found out. Experimental validation after modification of the beveling of the fan on noise levels was also carried out. The effect of the number of blades on the acoustic pressure field was studied experimentally.

Mirko Cudina[5] described that the noise spectrum consists of rotational and non-rotational noise for an axial fan. The fluctuating forces generated on the rotor blades contribute to the rotational noise of the axial fans. But it was observed that the non-rotational noise is dominating than the rotational noise. The modifications of fan geometry and operating conditions were carried out and its influence on the optimum fan design was also studied at various speeds and loads. Maaloum *et al.*[6] presented theoretical study using hydrodynamic approach on the tonal noise of propeller blades. Acoustic analysis was carried out using the Ffowcs Williams and Hawkings (FW-H) equation. The vortex surface method and aero-acoustic approach was used for prediction of unsteady hydrodynamic forces applied on the propeller blades.

Frid and Fehse[7] aimed at reduction of noise from the diesel engine cooler by modifying the airflow into the fans, reduced tip clearance *etc*. Noise reduction of baseline fans was obtained by modifying the type of flow, blade shapes and number of blades. Igarashi and Kitagawa[8] presented the application of CFD analysis on the flow fields of propeller fans. Their study focused on reducing the propeller noise from the flow duct located in a complex shaped duct, where they were subjected to higher pressure resistance. The study achieved large noise reduction and improved flow characteristics by changing the shape of a bell mouth and width of upstream duct.

Seol *et al.*[9], predicted non-cavitating noise of an underwater marine propeller using Potential-based panel method. For non-uniform flows, acoustic analysis is carried out in time-domain for a single and ducted propeller. Acoustic analysis is carried out using F fowcs Williams Hawkings equation. Kim *et al.*[10], Conducted experiments to predict broadband noise and developed a numerical method for predicting tonal noise of a propeller. A finite volume method is used for estimating the sheet cavitations. The propeller tonal noise is predicted by the distributed source model, based on the acoustic analogy and is verified with the water tunnel experiments.

From the literature review carried out, it is seen that very few studies were focused on marine propeller noise or its control. Thus, study presented in this paper is probably the first time that is reporting the effect of incremental thickness on marine propeller's noise and this is also perhaps for the first time verification of hydrodynamic performance of the propeller is reported along with identification of low noise propeller configuration.

3. NUMERICAL MODEL OF PROPELLER

3.1 Propeller geometry

Salient Geometric parameters of the propeller are listed below:

Diameter of propeller	0.389 m
Hub to propeller diameter ratio	0.254
RPM of propeller	780
Speed of inlet flow	7.08 m/s
Number of Blades	5 or 6

3.2 Solid Model

A propeller is a complex 3D geometry hence the modeling of propeller requires high end modeling tool. To generate a blade model, it is necessary to have sections of the profiles at various radii. The expanded sections drawn are moved along the radius of propeller to get respective skew angles and they are rotated to respective pitch angle at each section. The rotated sections are developed on the cylinder to get wrapped section at each radius. The Multi section surface is used to join all the profiles to get the blade modeled. Finally surface model is made into solid by closing all the surfaces edges and filling the volume between the surfaces with solid. The hub is generated by revolving the profile along the propeller axis and then the blade is joined with the hub. At the intersection of hub and the blades, the edge fillet is used to create the root around the blade where propeller blade and hub meets. The edges of the propeller are filleted to get smooth curved edges. The single blade modeled is used to generate remaining blades on the hub using circular array so that the equally spaced blade are obtained along the axis of the propeller. Solid models of 5 and 6 bladed propellers are shown in Fig. 1 and Fig. 2 respectively.

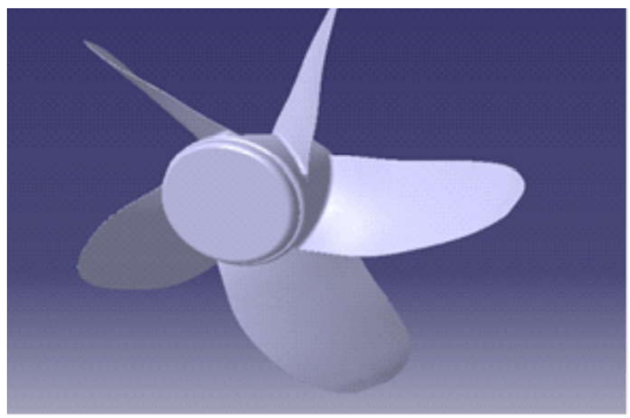

Fig. 1. Solid model of 5 Bladed propeller

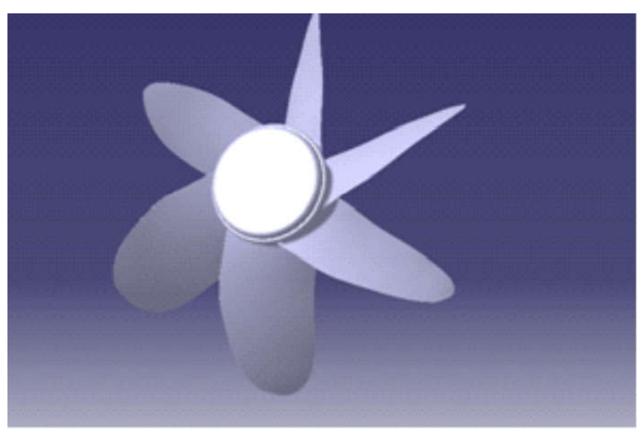

Fig. 2. Solid model of 6 Bladed propeller

3.3 CFD Model

Solid model of propeller generated as described in Section 3.2 was imported into CFD tool for structural meshing. To discretize the domain, three dimensional structural tetrahedral grids are generated. Tetrahedral element has been used for mesh consistency and for obtaining better results. Coarser grid is given for inner surfaces whereas finer grid is given for edge surfaces. Cell sizes near the blade tip is very small and are increased towards the hub to get the flow properties with better quality.

Fluid was chosen continuum and the water properties were assigned to it. Fluid model was generated using Finite Volume. Fluid Zone is considered as a cylinder extending either side of the bladed propeller. Cylinder walls are defined as stationary wall. Surfaces that rotate relatively are defined as moving walls. Moreover, as they are dependent on the fluid around them and as they rotate, they are defined as relative to adjacent cell zone and rotational motion.Inlet and outlet are defined as velocity inlet (7.08m/sec) and outflow. The inlet distance of 3D is chosen (where D is diameter of the propeller) from mid of the chord of the root section. Outlet is distance of 4D is chosen from same point at downstream. In radial direction, a distance of 4D is chosen from the axis of the hub. Fluid zone in the inner volume is defined as moving mesh and 780 rpm in x-direction The far field boundary was taken as inviscid wall and assigned an absolute rotational velocity of zero.

CFD model of fluid zone and meshed model of propeller are shown in Fig 3 & 4 respectively.

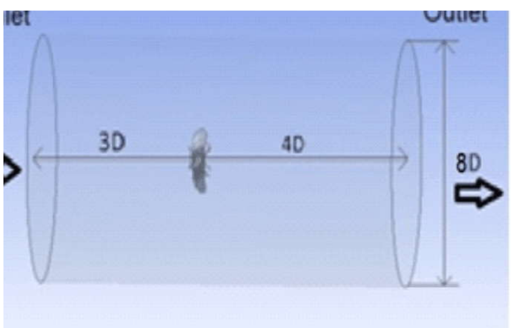

Fig. 3. CFD model of fluid zone

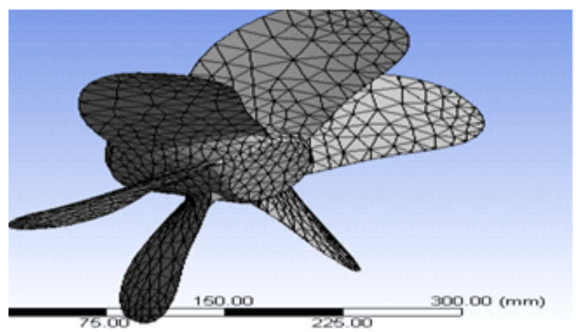

Fig. 4. Meshed model of propeller

The solution was computed by using the physical time derivatives. The chosen time step was to a rotation of one degree for the propeller for the finer grid. After convergence, there are 436445 tetrahedral elements in the inner volume (propeller volume) and 680134 tetrahedral elements in the outer volume (far field volume) respectively. For entire grid, the total number of cells generated after convergence was 1.2 million.

3.4 Turbulence model and Solver

Large Eddy simulation (LES) turbulence model was employed to simulate turbulent nature of the flow. In this method, large eddies are computed explicitly and the smallest eddies are modeled. The large-scale motions are responsible for the transport as they are more energetic than the small scale ones. LES technique solves the unsteady three-dimensional Navier-Stokes equations with an appropriate filtering procedure. LES requires higher computational cost than RANS (Reynolds Averaged Navier Stokes) due to extremely fine resolution of grid required to properly resolve the length and time-scales of the energy-containing eddies. LES when properly executed can directly resolve large-scale turbulent coherent structures. LES requires fine grid to predict the resistance of the models of high-Reynolds number turbulent boundary layers.

4. ACOUSTIC ANALYSIS

If the distribution of sound sources on the moving boundary (the blade surface) and in the flow field is known, then the noise prediction can be represented as the solution of the wave equation. This simulation was carried out using Ffowcs Williams Hawking (FW-H) formulation which is a far field integral method The FW-H equation is an inhomogeneous wave equation and is given below:

$$\frac{1}{a_0^2}\frac{\partial^2 p'}{\partial t^2} - \text{V2p}' = \frac{\partial^2}{\partial x_i \partial x_i}\{T_u H(f)\} - \frac{\partial^2}{\partial x_i}\{[P_u n_i + + pu_2(u_n - v_n)]\delta(f)\} + \frac{\partial}{\partial t}\{[P_0 v_n + P(u_n - v_n)]\delta(f)\}$$

Here, u_i is fluid velocity component in the xi direction,

u_n is fluid velocity component normal to the surface $f = 0$,

v_i is surface velocity component in the x_i direction,

v_n is surface velocity component normal to the surface,

$\delta(f)$ is Dirac delta function,

$H(f)$ is Heaviside function,

T_{ij} is Light hill stress tensor,

P_{ij} is compressive stress tensor,

P' is the sound pressure at the far field ($p' = p - p_0$),

f = 0 denotes a mathematical surface introduced to "embed" the exterior flow problem

A_0 is the far-field sound speed,

The solution of above equation is obtained using the free-space Green's function ($\delta(g)/4\pi r$). The complete solution consists of surface integrals and volume integrals. The surface integral consists of contributions from monopole and dipole acoustic sources and partially from quadrupole sources, whereas the volume integrals consist of quadrupole (volume) sources. The contribution of the volume integrals becomes small if Mach number is low. Therefore, surface integral solution only is considered, which is applicable to marine propeller as rotating speed is much lower compared to sound speed underwater. As brought out earlier, input parameters for acoustic analysis are obtained from the output of CFD analysis. Also, density of water and velocity sound in water are also given as inputs for acoustic analysis. Acoustic analysis is thus carried out using FW-H equation and noise levels are estimated as a function of frequency.

5. NOISE PREDICTION RESULTS

In this section, results of acoustic analysis carried out are presented. Validation of approach is brought out by verifying the noise prediction of base line propeller with experimetal data. Subsequently, results obtained for all other propeller configurations are presented.

5.1 Validation of methodology

Methodology brought out above has been employed initially for 6 bladed baseline propeller and noise levels estimated were validated experimentally using water tunnel facility available at NSTL. Corresponding results are shown in Fig 5. Noise measuremnts were carried out from 1 kHz-10 kHz due to low frequency limitation of the test facility. It may be observed that experimental and computational data are in reasonable agreement within engineering accuracy.

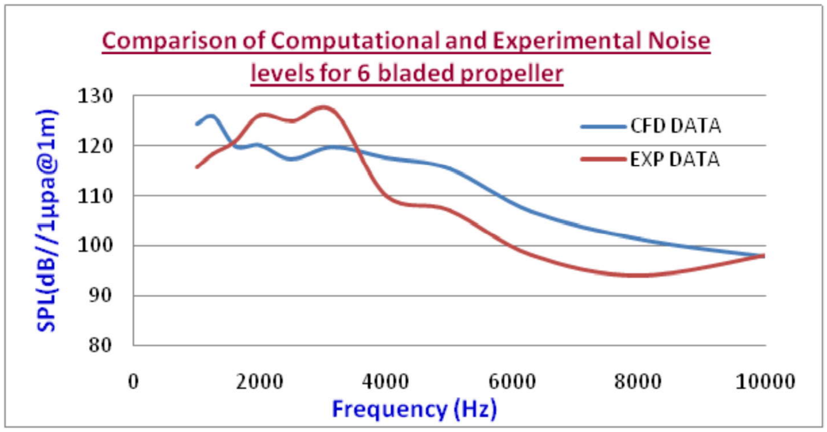

Fig. 5. Comparison of Computational and Experimental Noise levels for 6 bladed propeller

Having established veracity of the numerical methodology, it was adopted for all ten configurations studied in this paper. The configurations studied are 5 and 6 bladed propellers with varying blade thickness of 0.1 mm to 0.5 mm in steps of 0.1 mm.Though analysis was done fo all these configurations, predicted noise spectrum over the frequency range of 0-10 kHz for 5 and 6 blade propellers with 0.5mm increased blade thickness alone are shown in Fig 6 and 7 for brevity.

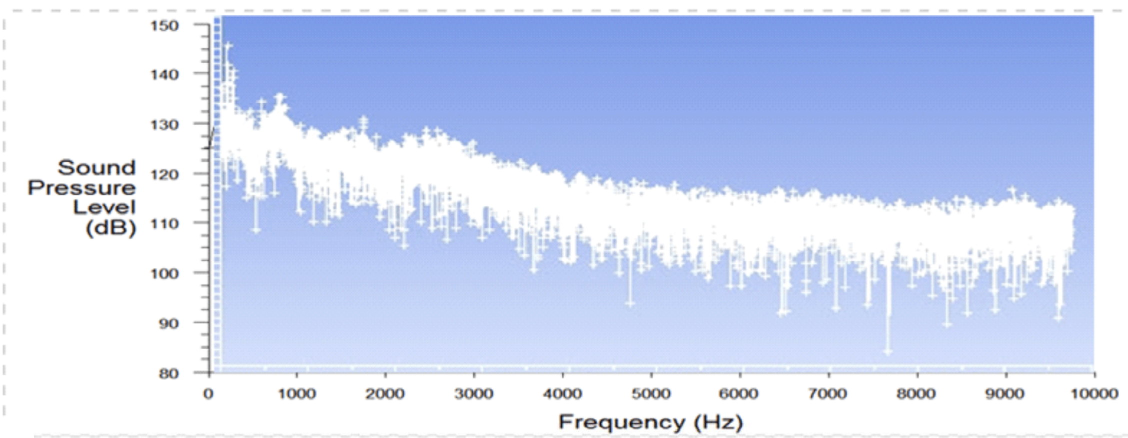

Fig. 6. SPL in dB ref 1µPa @1m for 5 Blade Propeller for 0.5mm increased blade thickness

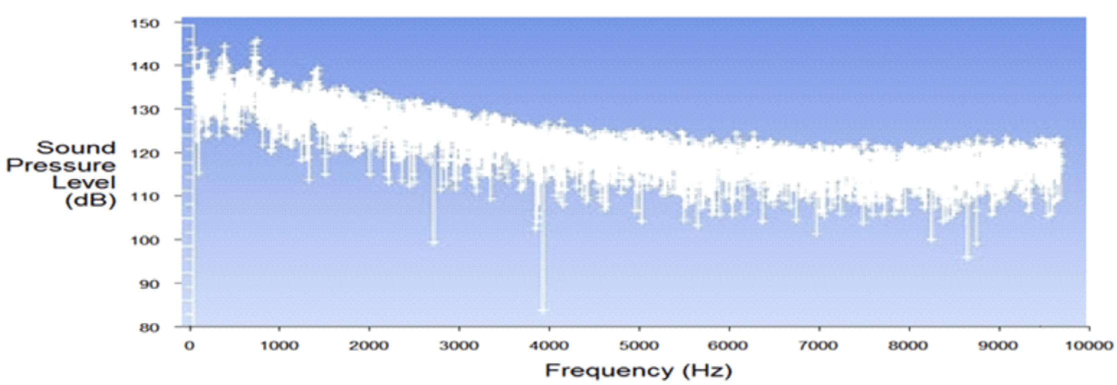

Fig. 7. SPL in dB ref 1µPa @1m for 6 Blade Propeller for 0.5mm increased blade thickness

5.2 Noise levels of 5 Blade propeller with different thicknesses

Table 1 shows results of noise of 5 bladed propeller with blade thicknesses increments from 0.1 mm to 0.5 mm of existing blade thickness.

Table 1: Noise levels of 5 bladed propeller

5 Bladed propeller Sound Pressure Level in dB ref 1μPa @1m @ 780 RPM					
Baseline thickness	0.1 mm increment	0.2 mm increment	0.3 mm increment	0.4 mm increment	0.5 mm increment
142	139	135	133	132	128

5.3 Noise levels of 6 Bladed propeller with different thicknesses

Table 2 shows results of noise of 6 bladed propeller with blade thicknesses increments from 0.1 mm to 0.5 mm of existing blade thickness.

Table 2: Noise levels of 6 bladed propeller

6 Bladed propeller Sound Pressure Level in dB ref 1μPa @1m @ 780 RPM					
Baseline thickness	0.1 mm increment	0.2 mm increment	0.3 mm increment	0.4 mm increment	0.5 mm increment
130	126	124	123	120	116

From the above, it is observed that there is significant reduction with thickness increments of blade for both 5 and 6 bladed propellers. It is also observed that reduction of noise is not linear with uniform increments of thickness. A maximum of 14 dB noise reduction is obtained by 0.5 mm increased thickness for both 5 and 6 bladed propellers compared to existing propeller. However, noise levels of 6 bladed propeller are much lower than those of 5 bladed propeller under the same conditions.

6. HYDRODYNAMIC PERFORMANCE

While designing marine propeller for low noise, it is important to check modifications do not compromise the basic functional hydrodynamic performance. Primarily Thrust and Torque are important parameters for a propeller. Thus, a check was carried out for Thrust and Torque coefficients of low noise propeller vis a vis base line propeller. Results are listed in **Table 3**.

Table 3: Comparison of Thrust coefficient and Torque coefficient

Propeller Variant	Total Thrust, T (N)	Density of water, ρ (kg/m$^{3)}$	Propeller speed, n (rps)	Diameter of propeller, D (m)	Thrust Coefficient K_T	Torque, Q (N-m)	Torque Coefficient K_Q
Baseline propeller	1363	1000	13	0.389	0.346	51	0.03366
Low noise propeller	2460	1000	13	0.389	**0.6358**	67	**0.04382**

From this Table, it is seen that both Thrust and Torque coefficients for low noise propeller are better than those of base line propeller. Thus, low noise propeller satisfied hydrodynamic performance requirement also.

7. CONCLUSION

Non-cavitating noise generated by underwater propeller was investigated by numerical method in this study. CFD and acoustic analysis were employed for this study on a chosen propeller to find noise levels at specified operating conditions. The turbulent nature of the flow was incorporated through the Large Eddy Simulation. Acoustic analysis was performed by solving FW-H equation with monopole and dipole source terms. Validation of methodology employed was carried out on base line propeller to establish its efficacy. Two variants of propeller (namely, 5 bladed and 6 bladed) were studied for noise performance through incremental thickness variation of the blade From the results it was observed that the 6 bladed propeller with 0.5mm increased thickness of blade generates lesser noise compared to all other propeller configurations studied. It is also seen that compared to the base line propeller, increasing blade thickness of propeller provides significant noise reduction.

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