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REVIEW PAPER

Normative Framework of Noise Mapping in India: Strategies, Implications and Challenges Ahead

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Abstract
The paper presents a retrospective and prospective view of noise mapping strategy followed across the globe as a diagnostic tool for controlling the noise pollution in urban cities. The concept of noise mapping is primitive in India and thus developing the noise maps is really a great challenge for big metropolitan cities of India. The paper discusses the benefits associated, input parameters required, methodology, sampling and interpolation techniques used, noise control action plans and challenges ahead for the development of strategic noise maps. The pros and cons associated with noise mapping and validity of principal traffic noise models in India are presented. Also, various technical aspects pertaining to noise mapping are clarified in Indian perspectives based on the standard operating procedures used internationally. This paper recommends a national policy framework of noise mapping and control for Self-Reliant India (Aatmanirbhar Bharat) and shall serve as a guiding document to all the stake holders for noise mapping of the larger parts of the country.

Keywords Noise mapping · Interpolation technique · Sampling strategy · Noise control action plan

1 Introduction

Noise mapping is an important tool for urban planning for assessment, management and control of ambient noise levels. The effects of increasing noise levels on human health have been evident from the various recent studies [1–3]. The World Health Organization (WHO) estimated that in Western Europe alone, one million healthy life-years are lost annually to environmental noise [4]. Thus, it is imperative to monitor and assess the ambient noise levels and devise strategies for noise pollution control. The European Noise Directive 2002/49/EC (END) had introduced two new instruments for urban planning and noise management: strategic noise maps and action plans. One principle of the Directive is monitoring the environmental problem by requiring competent authorities in Member States to draw up "strategic noise maps" for major roads, railways, airports and agglomerations, using harmonized noise indicators L_{den} (day-evening-night equivalent level) and L_{night} (night equivalent level). These maps will be used to assess the number of people annoyed and sleep-disturbed, respectively, throughout Europe [5]. A strategic noise map is a map designed for the global assessment of noise exposure in a given area due to various noise sources for overall noise predictions for such an area. A strategic noise map is a presentation of data on the noise situation in terms of noise indicators like L_{den} and L_{night}; exceeding of a limit value; estimated number of dwellings exposed to specific values of noise indicator; and the estimated number of people exposed to noise. Thus, the noise mapping is primarily concerned with the presentation of noise data, while the strategic noise mapping is focussed on assessment of noise exposure [6–9]. The assessment of exposure to environmental noise is to be achieved through harmonized noise indicators, L_{den} (day-evening-night equivalent sound pressure levels) and L_{night} (night-time equivalent sound pressure levels). European Noise Directives 2015/996 clarifies some issues on noise mapping and requires all the Member States to transpose CNOSSOS-EU calculation method by 1st January, 2019 [10]. There had been many such studies reported in Europe and other countries as well on developing the noise maps of various cities [11–15].

In India, the concept of noise mapping is very new in its primitive stages. The health outcomes of noise levels

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Table 1 Recommended health outcomes for noise health impact assessment (HIA) for road, rail and air traffic (WHO [16])

Source	Outcomes that can be quantified in a HIA	Outcomes that can be potentially quantified in a HIA
Road	Incidence of ischaemic heart disease Annoyance Sleep disturbance	Incidence of stroke Incidence of diabetes
Rail	Annoyance Sleep disturbance	
Air	Annoyance Sleep disturbance Reading and oral comprehension in children	Incidence of ischaemic heart disease Change in waist circumference

Table 2 Ambient noise standards in India [20]

Area code	Category of area/zone	Limits in dB(A) L_{eq}^{*}	
		Day time	Night time
A	Industrial area	75	70
B	Commercial area	65	55
C	Residential area	55	45
D	Silence zone	50	40

1. Day time shall mean from 6 AM to 10 PM

2. Night time shall mean from 10 PM to 6 AM

3. Silence zone is defined as areas up to 100 m around such premises as hospitals, educational institutes and courts. The silence zones are to be declared by competent authority. Use of vehicular horns, loudspeaker and bursting of crackers shall be banned in these zones

4. Mixed categories of areas may be declared as one of the four above-mentioned categories by the competent authority

5. L_{eq}: It is an energy mean of the noise level over a specific period

Table 3 Ambient noise standards for airport noise zone in India [21]

Type of airports	Limits in dB(A) L_{eq}	
	Day time	Night time
Busy airports	70	65
All other airports excluding proposed airports	65	60

due to various transportation noise sources as enlisted in Table 1 had been evident and thus makes it imperative to fight with increasing noise pollution especially in metropolitan cities [16]. The establishment of National Ambient Noise Monitoring network since 2011 had been a major initiative taken by the Central Pollution Control Board for long-term noise monitoring of seventy sites in seven major cities of India [17–19]. The comparison of the noise monitored data with the ambient noise standards (Table 2, [20]) shows that the majority of the sites lying in the residential and silence zones do not meet the ambient noise standards. Recently, the ambient noise standards for airport zones have been also formulated as shown in Table 3 [21]. There have been very few studies reported on noise mapping and control in India as described in Table 4 although long-term and short-term noise monitoring of specific sites/locations has been widely reported [22–36]. The National Green Tribunal (NGT), Delhi in his orders dated 15th March, 2019 has directed Central Pollution Control Board (CPCB), India to prepare noise pollution maps and identify the hot spots and propose a remedial action plan. Noise mapping has been also made mandatory in Indian mines [37]. The concept of noise mapping is a comprehensive approach involving the following steps [38]:

- Collecting the raw data, preparing and storing of the data,
- Computing the noise levels in a computer model,
- Cumulating the noise levels (when there are different sources)
- Determining noise contours;
- Determining noise effects;
- Presentation of the impact of noise.

Although understanding the noise scenario, identification of hot spots and determination of noise impact of various noise sources are the key stages of noise mapping, however, without the consideration and implementation of noise control measures or Noise Action Plans (NAPs), the studies would be incomplete and inefficacious. There has been no comprehensive discussion on the various aspects so far pertaining to development of a harmonized noise mapping approach, use of principal traffic noise model or software validated in Indian cities, sampling strategy to be followed, representation of noise descriptors, national policy framework for noise abatement and control in India. The present paper may be envisaged as a “White Paper on Noise Mapping in Indian perspectives” highlighting and recommending the various aspects associated with developing noise maps to understand the noise scenario and initiate noise control action plans in Indian perspectives. The major consideration of the present work is to standardize and harmonize the noise mapping approach and associated issues in Indian perspectives for the development of noise maps of various cities and controlling the noise pollution with a key objective of

Table 4 Review of noise mapping studies reported in Indian scenario so far [22–36]

Researcher	Study area	Noise mapping method used	Remarks or conclusions
Kalawapudi et al. [22]	Nine major cities of Mumbai metropolitan region	Noise monitoring at 153 locations were undertaken and geospatial noise maps were developed	Silence zones have been the worst affected areas
Sonaviya and Tandel [23]	South-west and central zone of Surat city	RLS-90 mathematical model inbuilt in Sound-PLAN software was used	Horn honking correction factor improves the accuracy of RLS-90 mathematical model
Konadath et al. [24]	Mysore city	Isopleth map drawn in Arc GIS in conjunction with kriging interpolation method	Ambient noise levels were correlated with land use
Laxmi et al. [25]	Nagpur city of Maharashtra	Noise monitoring at 700 locations was conducted using a sound level meters mounted on cycles	Study recommended that cycle-based noise monitoring is effective way to assess noise pollution
Sonaviya and Tandel [26]	Surat city of Gujarat	The computer simulation model (Sound PLAN software) is used to develop noise maps	L_{Aeq} levels increase by 0.5–8 dB(A) due to horn events
Manoj Kumar et al. [27]	Vellore city located in Tamil Nadu state	Noise levels at six locations were recorded and noise maps using IDW were developed	Noise maps showed alarming noise levels near sampling sites
Das et al. [28]	English Bazar Municipality (EBM)	Noise level-based digital elevation model (DEM) technique in ERDAS Imagine (v.9.2) environment is used.	Traffic noise (58.65%) is the most disturbing noise nuisance followed by construction work (21.15%).
Debnath and Singh [29]	Dhanbad township area	Noise mapping was done using ArcGIS 10.3 software for better visual information of the noise environment.	Noise contour maps were developed
Lokhande et al. [30]	Major operational mines in the Keonjhar, Sundergadh, and Mayurbhanj districts of Odisha, India.	A study area map was generated and imported into the Predictor LimA Software for noise prediction and developing a noise map of the entire study area	The noise produced by mechanized mining operations was observed between 74.3 and 115.2 dB(A)
Lokhande et al. [31]	Mines in the Northern Keonjhar district.	With the utilization of Predictor LimA Software, noise contours were developed	The mitigation measure is proposed
Manwar et al. [32]	Mechanised mine for a cement plant	Predictor LimA Software was used for $10\,m \times 10\,m$ grid	Residential areas near the crusher plants were vulnerable to increased noise propagation
Akhtar et al. [33]	Preselected Locations of New Delhi	Noise monitoring followed by horizontal and vertical GIS presentation of noise maps	Equivalent sound level ranges from 67.4 dB(A) to 82.3 dB(A)
Alam [34]	Guwahati, Assam	Noise maps were prepared using Arc GIS 9.3.1 software, kriging interpolation algorithm was used	Places with high traffic congestion, narrow roads showed high noise levels
Banerjee et al. [35]	Asansol city of West Bengal, India	Multispec was used along with GRAM++ GIS software using interpolation (ordinary kriging) method	The study revealed schools and hospitals were subjected to significantly high noise level throughout the day
Kalaiselvi and Ramachandraiah [36]	Chennai city	Sound Plan software was used in this study	A separate multiple regression model is developed

promoting good health through the effective noise pollution management and control. The present paper thus presents the pros and cons associated with noise mapping in India with the following objectives:

- Developing a harmonized approach to be followed for noise mapping for understanding the noise scenario and devising noise abatement action plans for controlling the noise pollution in the metropolitan cities in India,
- Ascertain the usability and suitability of principal traffic noise models (TNMs) developed in other countries in India,
- Presents pros and cons associated with noise mapping and clarifying the technical aspects that are still not very clear to the stakeholders based on the standard operating procedures followed internationally and
- Recommends a national policy framework in India for noise monitoring, mapping and control for Self-Reliant India (Aatmanirbhar Bharat).

2 Noise Mapping: Strategy and Implications

A noise map is a graphical representation of the sound level distribution prevailing in an area under study. The noise maps may be drawn based on actual measurements at various sites utilizing a predetermined sampling strategy or may be plotted using a validated noise model integrated with Geographical Interface Systems (GIS). Figure 1 shows the benefits associated with noise mapping. Mapping can be done exclusively for individual noise sources like road traffic, railways, aircraft, industry, etc., or in combination with all the sources for an area under study so as to present an overall noise scenario of the site [33]. "Strategic noise map" is a map designed for the global assessment of noise exposure in a given area due to different noise sources or for overall predictions for such an area (European Directive 2002/49/EC, Article 3, letter r). The European Noise Directives (END) requires Member States to produce strategic noise maps for the main sources of environmental noise, i.e. major roads, major railways, major airports and agglomerations. In Indian perspectives, the primary concern would be noise monitoring of the sites and ascertaining their legal compliance with respect to the ambient noise standards based on the category (or zone) of that area (Table 2). The pictorial view of measured noise levels in terms of noise maps can better represent the noise scenario and devising control action plans. The conceptual framework of the noise mapping process is shown in Fig. 2a, similar to that discussed in a report of the European Environment Agency [39]. The Geographical Information Systems (GIS) is the central database management engine, whereby the noise mapping software must be able to read and write data formats compatible with the GIS [8]. The noise data obtained

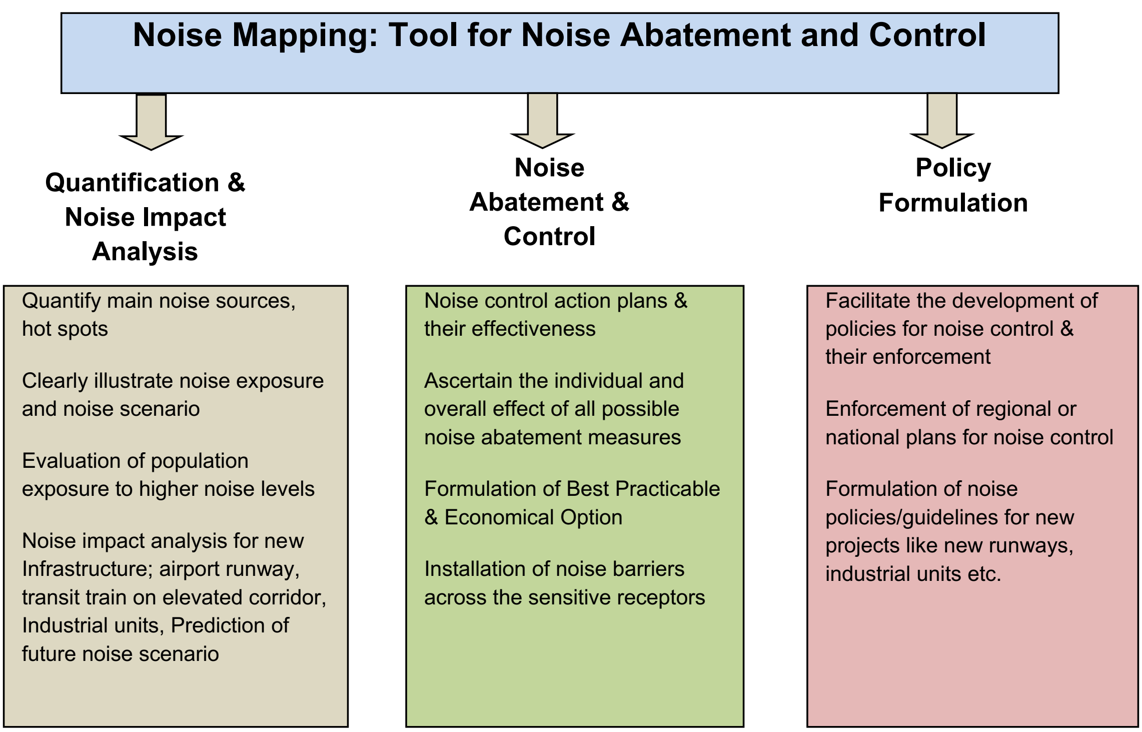

Fig. 1 Noise mapping: an indispensable tool for noise mapping and control

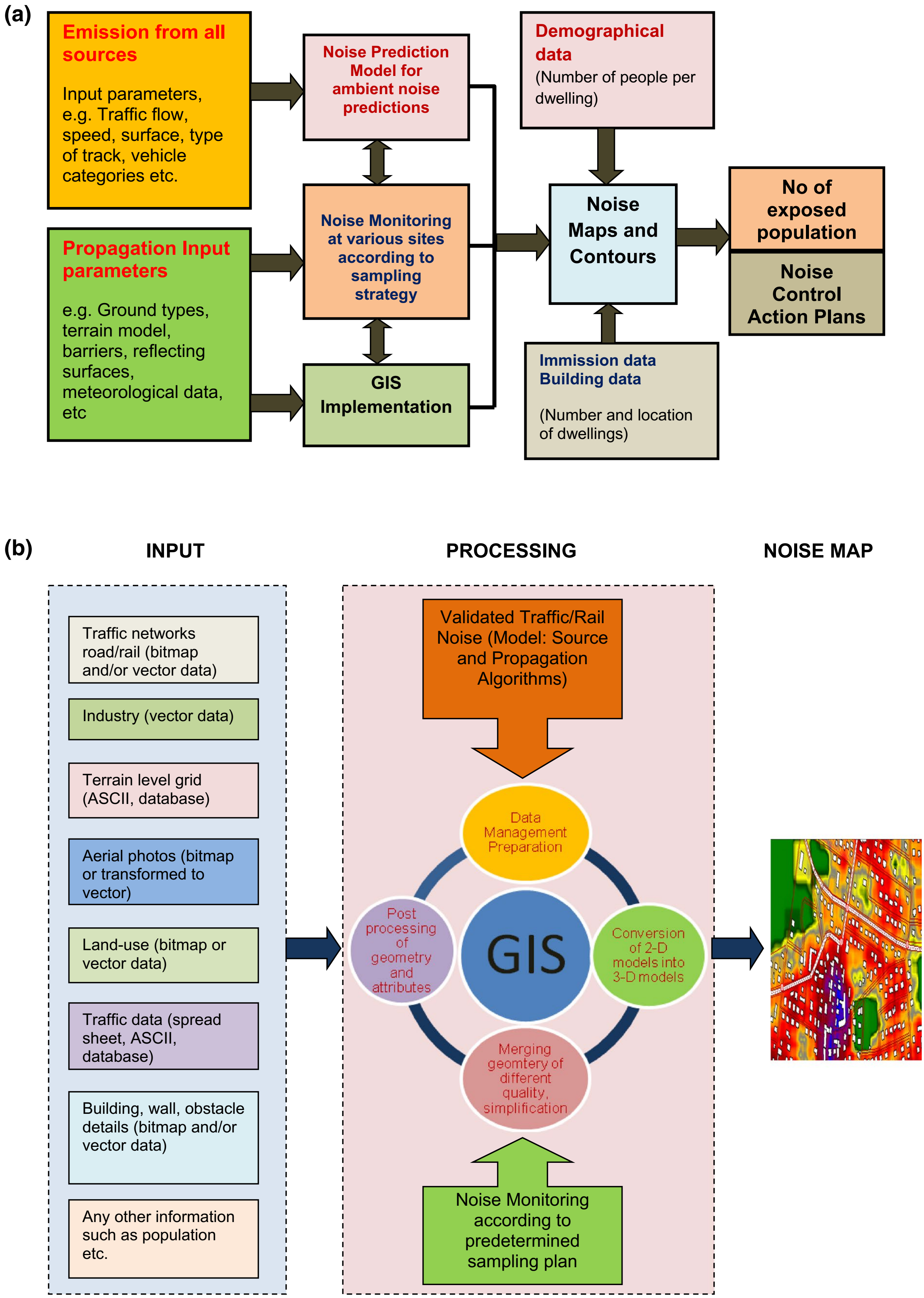

Fig. 2 **a** Conceptual framework of the noise mapping process and ambient noise levels control in cities. **b** Coupling GIS and noise mapping

either through the measurement or calculation methods can be stored as a separate layer and can be overlapped onto the existing geographical information thus facilitating a visual representation in terms of noise contours or isopleths [24, 40]. The coupling of Geographical Information Systems for 2D and 3D noise mapping is one of the prime considerations for developing the noise maps of an area or a city as shown in Fig. 2b similar to that presented in Good Practice Guide for Strategic Noise Mapping [8]. The geospatial data pertaining to topography, building height and type, road network, ground surface, etc.; traffic data (number of vehicles, category and average speed), road surfaces and information about other aspects such as building facades, noise barrier, etc., are essentially required for developing accurate and precise noise maps. Table 5 discusses the parameters required for noise mapping of a particular site. However, the noise mapping strategy is not as easy as it looks. There are various aspects taken into consideration for noise mapping such as measurement considerations, Digital terrain model and input parameters required, validated traffic noise model, spatial interpolation method, sampling strategy and colour code to be used.

2.1 Measurement Considerations

The ISO 1996-2 standard [41] recommends that for noise mapping, the microphone height must be 4.0 ± 0.5 m in residential areas with multistorey buildings and 1.2 ± 0.1 m or 1.5 ± 0.1 m in residential areas with one-floor buildings and recreational areas. Also, the European Noise Directives (END) states that when calculations are carried out for developing strategic noise maps, the assessment point must be 4.0 ± 0.2 m in height above the ground level. The standard estimates a minimum uncertainty of 2 dB in measured noise levels owing to various factors such as instrumentation, operating conditions, weather and terrain conditions and residual sound [42].

2.2 Digital Terrain Model and Input Data Required

The key stage in this process is the understanding of the area under review. The digital terrain model of the area under consideration, source characteristics, details of the surroundings (road surface, number of building and their heights, street width, absorption coefficient of facades), meteorological and demographic data are the prior vital input parameters required for developing 2D or 3D noise maps.

2.3 Spatial Interpolation Methods

Mapping involves the formation of grid points, measuring or calculating the noise levels at these points and calculating the noise levels within these points by employing appropriate interpolation method. The spatial interpolation techniques such as inverse distance weighted method (IDW) and kriging interpolation method are widely used for interpolation. Spatial interpolation of noise receivers had been reported by utilizing various techniques such as kriging, IDW methods and empirical Bayesian kriging (EBK) as summarized by Banerjee et al. [43]. The suitability of the interpolation algorithm can be ascertained by cross-validation that involves the comparison by repetitively removing a known point from the data set, predicting its value by using remaining known points and interpolation method and ultimately computing

Table 5 Parameters required for noise mapping

Source	Traffic noise	Type of vehicles
		Average velocity
		Total traffic volume
	Industrial noise	
	Railway noise	
	Aircraft noise	
Surroundings	Road surface	
	No. of buildings and their heights	
	Street width	
	Absorption coefficients (facades)	
Meteorological	Temperature	
	Humidity	
	Wind speed	
Demographic	No. of inhabitants	
Digital terrain model	Importing shape and database files from Google Earth, creating an overlaying tile-pattern for the whole area, online geo-referenced maps as background maps	
Sampling strategy	Grid size or categorization sampling	
Software pre- and post-processing	Open Source GIS tool, provides automated processing of noise maps	

the error in noise prediction by comparing the estimated value from the known value of the given point [43]. IDW method is more deterministic and should be used when there is an initial dense set of points as it can capture the local surface variation, whereas kriging assumes a stationary and stochastic approach and provides the user with more options when controlling for the final outcome [44]. However, IDW being a weighted average interpolated of the nearest reference points provides satisfactory results when the number of elevation points in an area is large and the points are uniformly distributed [45, 46].

2.4 Sampling Strategies

The sampling strategies reported most commonly used by different researchers (grid, legislative road types and categorization methods) may be logically utilized considering the infrastructural and time constraints. Grid-based methodology is the traditional approach followed widely wherein a grid is overlaid on the map of the site to be mapped and nodes of the grid represent the measurement or calculation points. Grid size values higher than 400 m involve uncertainties of calculated values greater than 2 dB [13]. ISO 1996-2:2007 recommended that in case the difference between two nodes is greater than 5 dB(A), an additional sampling point is required to be measured between the two points. However, the categorization approach required significantly less measurements points as compared to grid-based method and is based on the assumption of road traffic being the dominant noise source in streets and cities. The categorization sampling of a city involves the street/road classification into the various predetermined categories [47]. A precise description of the various categories and summary of the steps for classification of the streets/roads have been described by Morillas et al. [48], whereby six classifications of the streets were reported for five medium-sized Spanish towns based according to their use in communicating the different zones of the town. In one such study reported by Morillas et al. [49], while only 60 sampling points were needed for categorization method, for the grid method, 215 sampling points were required for city of Cáceres, Spain (10 km^2 approx,. 95,000 inhabitants).

2.5 Noise Model and Mapping Software

The noise map provides the baseline data pertaining to the noise scenario for town planners, legislative bodies, architects and researchers for the planning and execution of new projects. The development of maps can be either through the noise monitored data or by virtue of the validated noise model. Many countries have developed their own validated noise prediction model [50, 51]. In some of the commonly used modelling packages such as CadnaA, Sound PLAN, Predictor-LIMA, the user may select any of the road traffic noise model (TNM) for noise predictions and generating maps. The accuracy of input data, noise modelling software (NMS); usability and validation and the calibration of generated noise maps are the key issues for reliable predictions and forecasting. The major benefit accomplished using such a software is the simulative platform that can be helpful in devising the noise control action plans for controlling the ambient noise levels for a particular area or site under consideration.

Figure 3 shows the flow chart depicting the noise mapping strategy. The selection of suitable locations based on a definite sampling plan in conjunction with long-term and short-term noise monitoring, followed by interpolation strategy, would be helpful to generate cross-sectional grid noise maps for different parts of the city. Eventually, all these maps can be integrated into a single map that depicts the noise scenario and would be helpful in devising the control strategies for environmental noise abatement and control. Amongst all the feasible noise action plans, the *BPEO* (Best Practicable and Economical Option) must be exercised based on cost–benefit analysis. The use of different colours depicts the various noise bands on a noise map. Generally, range of 5 dB, i.e. says 65–70 dB, is widely used. The only consideration should be that there should be sufficient discrimination between the colours to avoid duplicity. Also, a standardized colour code scheme followed in a country makes it easier and simple to compare the maps from different cities. An illustrative example of noise map of a specific site (Pusa road in Delhi city) is shown in Fig. 4 depicting the ambient day equivalent noise levels at peak times during the day.

3 Accuracy and Validity of Noise Models

Noise models have been developed for different sources of transportation noise and utilized by many countries in recent times. A list of some of these recent models used in various countries for different noise sources is summarized in Table 6 based on extensive review of the various recent studies [50–58], especially that from Kumar [52] study. Garg and Maji [50] described details of all the road traffic noise models such as CoRTN (Calculation of Road Traffic Noise) model of the UK, the Federal Highway Administration (FHWA) model of the USA, the RLS90 model in Germany, ASJ RTN 2008 of Japan, HARMONOISE model used in Europe. It may be noted that each of these models has been validated by the respective countries prior using them. In Indian perspectives, there is no validated noise model so far. As such, it becomes imperative to investigate the suitability of the various principal noise models in Indian context. There have been many such studies reported wherein CoRTN, RLS 90, FHWA model had

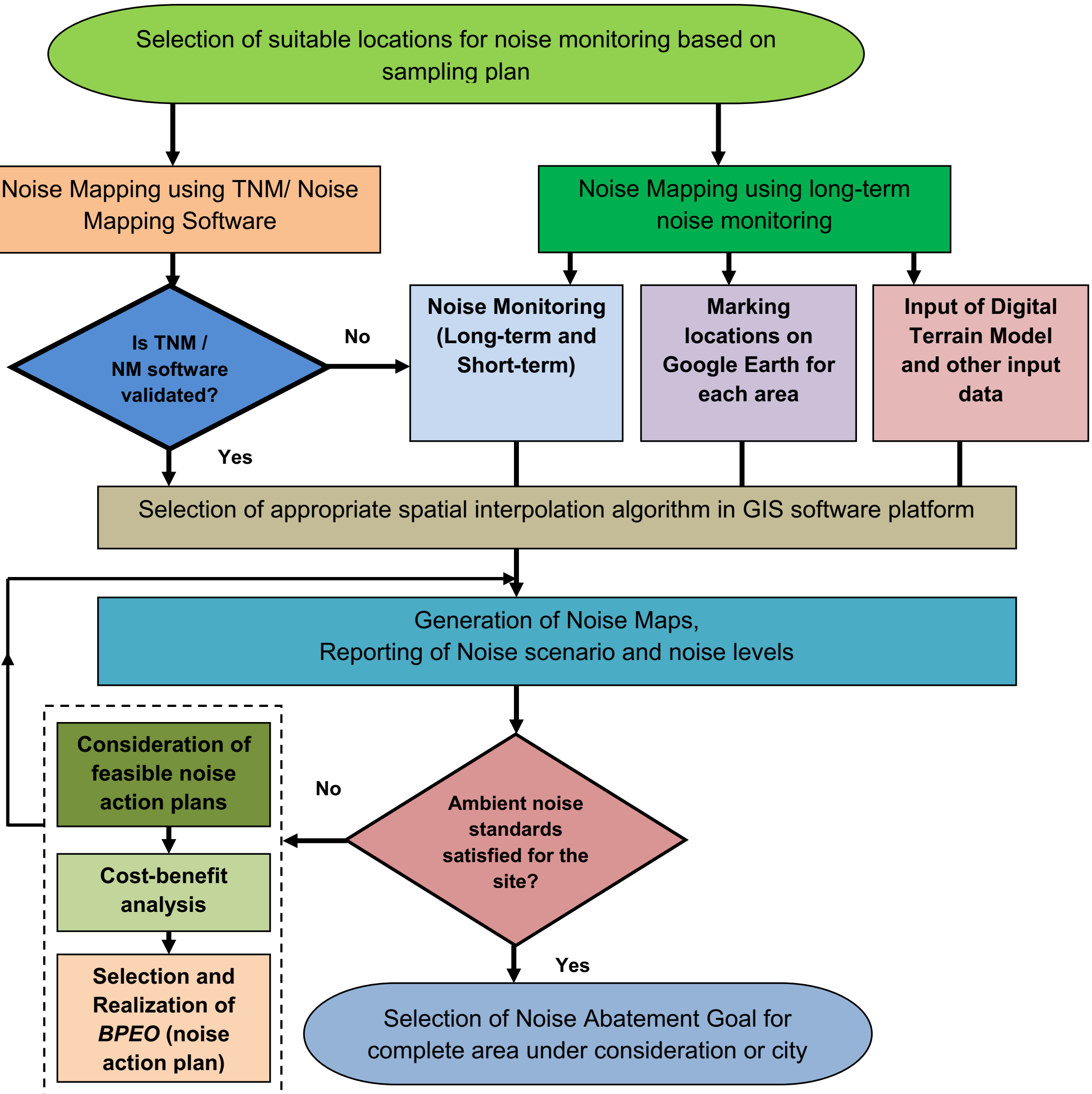

Fig. 3 Flow chart depicting the noise mapping strategy

been employed for short-term traffic noise predictions. For instance, a recent study by Lokhande et al. [59] in Nagpur city of India reported the error range of 1.6–2.1 dB(A) for $L_{\mathrm{Aeq,T}}$ predictions utilizing the FHWA model. Mishra et al. [60] reported the percentage variation in the range of 0.5–5.8% using the RLS 90 model for some sites in Delhi city. Similarly, CoRTN model had been used in a recent study reported for Vellore city, whereby a marginal difference [< 1.9 dB(A)] between the measured and predicted levels was observed [27]. However, a variety of factors such as heterogeneous mix traffic, honking noise, driving style and behaviour, different vehicular types and category, traffic congestion and road types that makes it imperative to either calibrate the other models or develop an indigenous noise model well suited for Indian conditions. For instance, a recent study reported by de Lisle [51] showed that CoRTN resulted in high over-prediction, TNM and NMPB produced similar results and ASJ RTN resulted in higher under-prediction. The use of a particular software package may also influence results as some studies reported that different software packages applying the same standard may also yield significantly different results [61, 62]. The different implementation of the propagation under homogeneous and favourable atmospheric conditions in noise modelling software may also cause differences in noise predictions [63]. Also, these models may be efficaciously employed for short-term sound level predictions, but for the long-term day and night equivalent level predictions, the accuracy of model and the input data such as traffic flow, vehicular speed, etc., is very vital for

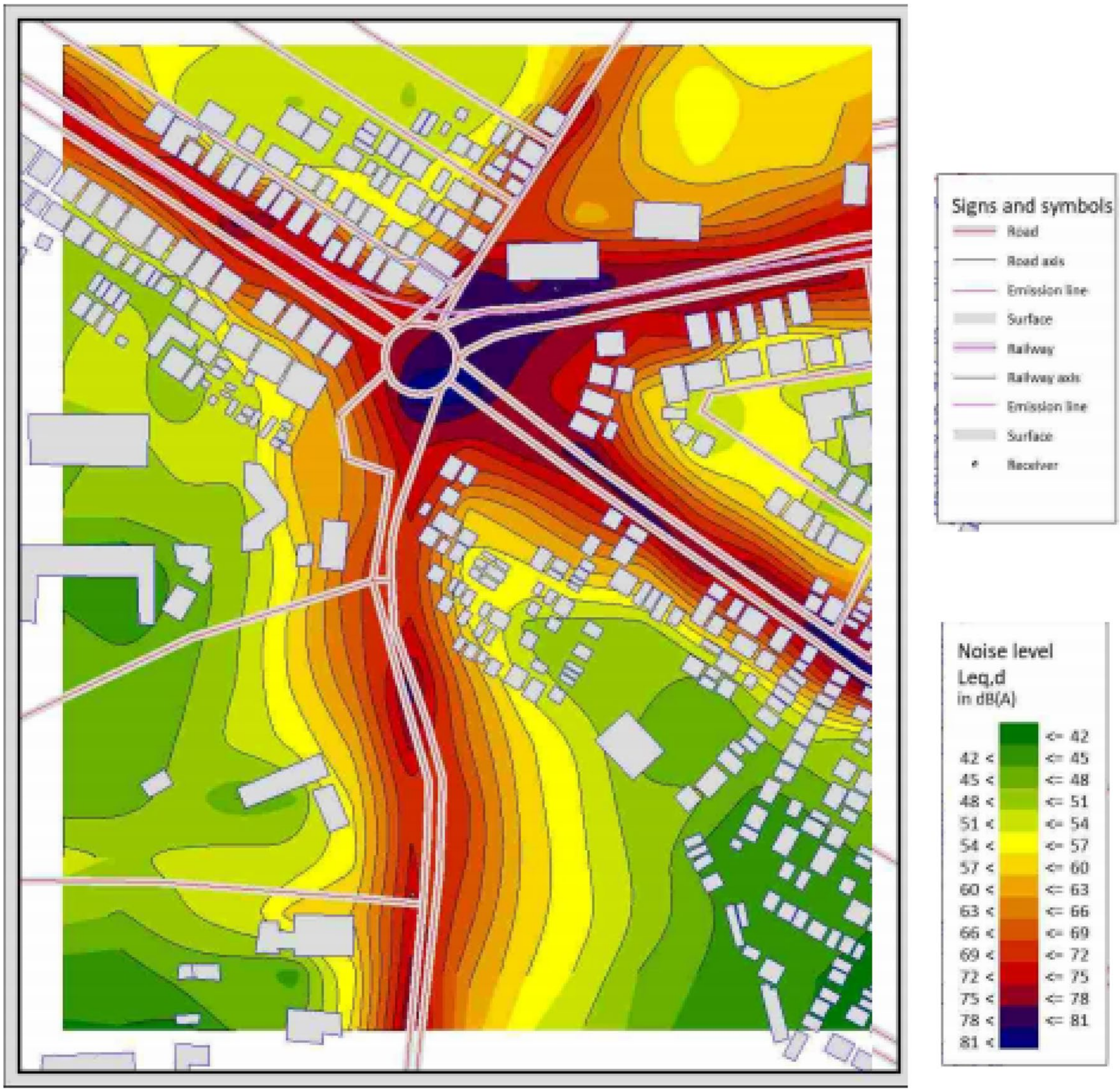

Fig. 4 A typical noise map generated for Pusa road site in Delhi city of India

reliable predictions with minimal errors. A traffic noise model (TNM) calculator sheet in MS Excel for the various principal traffic noise models was developed. Table 7 shows the statistical analysis of comparison of predicted sound levels from the various principal traffic noise models in comparison with the measured values of $L_{Aeq,T}$ for 51 data sets. It can be observed that the root mean squared error lies between 3.2 and 4.6 dB(A) for all these models. Consequently, the validity and usability of noise mapping softwares like CadnaA, Sound PLAN, Predictor-LIMA, etc., that are equipped with algorithms of all the principal traffic noise models are to be ascertained in India prior to utilizing them for noise mapping studies. The use of different software packages with the same input data may show significant differences [14]. It is imperative that the complete standardization and harmonization in noise predictions would inculcate the use of the same calculation model and software format in India [64–67].

4 Noise Action Plan and Noise Control Policy

The societal cost of rail and traffic noise had been estimated as 40 billion Euros per year in Europe, which is nearly 0.4% of the gross domestic product [68]. The Organisation for Economic Co-operation and Development (OECD) recommended a noise depreciation index of 0.5% of property value per decibel increase if noise levels are above 50 dB(A) L_{eq} (24 h) [69]. A US study estimated traffic noise costs at $21 annually per housing unit per decibel increase [70]. Thus, it is inevitable for every country to have a strong noise control policy that has a prime objective of preventing and

Table 6 Calculation noise assessment methods used across various countries [50–58]

Road	Rail	Air
RVS 04.02.11 (Austria)	ONR 305011 (Austria)	OAL Guideline No 24-1 (Austria)
NMPB-Routes-2008 (France)	RMR (Belgium, Bulgaria)	ECAC.CEAC Doc 29-3rd edition (France, Finland, Croatia, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Portugal, Slovakia, Slovenia, Sweden)
NMPB-Routes-96 (Bulgaria, Czech Republic, Italy, Poland, Spain)	Nord 2000 (Denmark)	Integrated Noise Model (INM) Version 7.0b (Belgium)
VBUS (Germany)	RMR (Ireland, Italy)	Integrated Noise Model (INM) Version 7.0d (Ireland, Italy, Portugal, UK)
CRTN (UK)	NF S31-133 (France)	VBUF (Germany)
CNOSSOS-EU (Finland)	CNOSSOS-EU (Finland)	CNOSSOS-EU
Nord 2000 (Denmark)	Nord 2000 (Denmark)	Aviation Environmental Design Tool (AEDT) (U.S)
UT2.1-302 (Hungary)	CRN (UK)	
RMV (Netherlands)	MSZ-07-2904:1990 (Hungary)	
FHWA TNM (USA)	VBUSch (Germany)	
ASJ RTN 2018 (Japan)	Schall 03 (Slovakia)	
sonROAD18 (Switzerland)	MPVHD (Czech)	

Table 7 Statistical analysis of the comparison of predicted $L_{Aeq,T}$ values from the various principal traffic noise models (TNM) in comparison with the measured values

Parameters	CNOSSOS-EU	RLS 90[a] model	HARMONOISE Model	FHWA[a] model	ASJ RTN 2008 model
Mean absolute error in dB(A)	3.9	2.6	3.6	3.1	1.6
Root mean squared error in dB(A)	4.6	3.2	4.0	3.7	3.3
Maximum error in dB(A)	5.2	3.8	0.8	2.8	5.3
Minimum error in dB(A)	−4.1	−6.9	−8.6	−7.9	−10.1
Correlation coefficient, R	0.59	0.68	0.63	0.69	0.53

[a]Distance correction applied to the models for comparison with measured value

reducing the negative effects of noise on human health. Thus, it implicitly defines the need of noise action plans for areas having accentuated ambient noise levels above the legal limits. The most cost-effective measures in a given situation are usually a mix of measures at the source and at the receiver [71]. The European directives on environmental noise recommend that authorities should design, implement and execute action plans against urban noise so as to reduce the exposure to environmental noise and thereby mitigate the effects associated with it such as sleep disturbance and annoyance. The notion of acoustic planning was introduced that refers to controlling the future noise by planned measures such as land-use planning, traffic planning, noise control at source and sound insulation measures [7]. Noise action plans help to structure and prioritise noise control measures through understanding the noise scenario, prioritizing of control measures, as well as involving stakeholders and the public. The traffic relocation plan, such as construction of a bypass highway, could be a useful mitigation measure that shows a significant decrease in noise levels up to 5 dB(A) [31]. Reduced travel demand evidently leads to a significant reduction in the population exposure to urban environmental noise as reported by Murphy and King [72]. The potential reduction can be accomplished by erection of noise barriers in areas having high ambient noise levels. The other potential action plans as highlighted by Torija et al. [73] include source control such as travel demand reduction, framing restrictive speed limits and prohibition of heavy vehicles in residential and sensitive areas, periodic noise emission testing of vehicles; mobility management for encouraging the use of public transport facilities and elimination of traffic congestions; urban planning such as land-use planning and management, e.g. zoning, pedestrianization of urban centres, etc., and inculcating education and mass awareness would be some of the vital steps in this regard. Figure 5 shows the various noise control measures that can be helpful for reducing the ambient noise levels in urban areas. However, the cost–benefit analysis or cost-effectiveness is the prime consideration for execution and would provide a useful framework and tool in developing the action plans. Figure 6

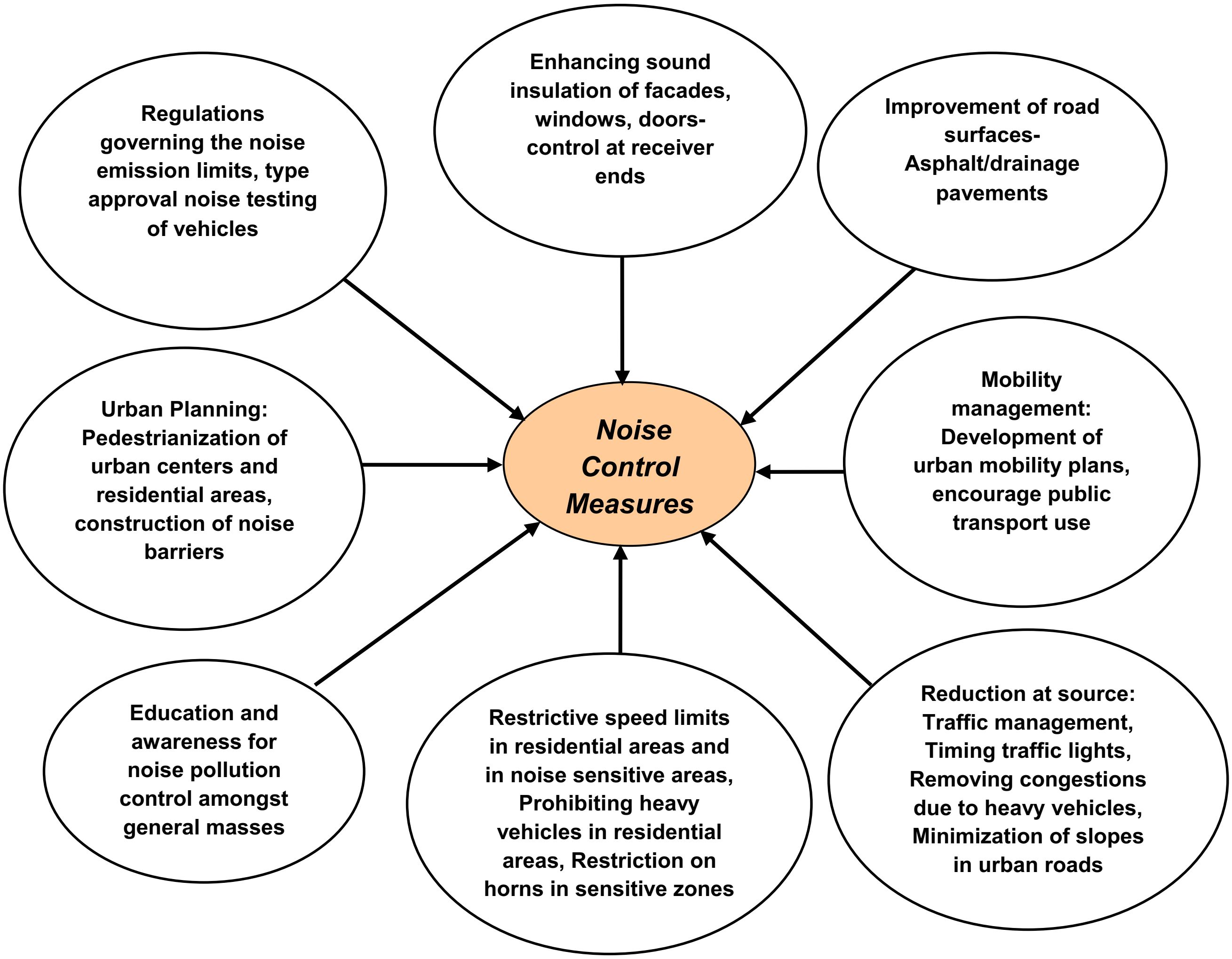

Fig. 5 Noise control measures for ambient noise level control in urban areas

shows the cost-effectiveness of various noise abatement approaches as highlighted in Münzel et al. study [74, 75]. It can be observed that quiet road surface stands to be the highest in cost-effectiveness, while building sound insulation and noise barriers have lower scores.

An effective noise policy for sustainable environment and integrating noise abatement planning into urban planning processes is highly required in Indian perspectives for accomplishing the desired goals. The policy measures may differ at local and national levels in terms of cost-effectiveness and suitability. For instance, spatial planning as a preventative noise control measure may be considered as an optimal approach at local levels but has different implications on national levels. The establishment of a harmonized national policy at both regional and national levels would provide a synergetic, consistent and co-ordinated approach towards noise pollution control in the country. In addition, the synergy between different measures and strategies such as air pollution control programme, Swatch Bharat mission should be there with involvement of all stakeholders and public participation. The Working Group on Health and Socio-Economic Aspects recommended a value of the perceived benefit of noise reduction of 25 Euro/household/dB/year in Europe [76]. Evidently, this quantification can be translated into Indian perspectives also as a co-ordinated approach with harmonized national policy framework for sustainable urban mobility plan and noise pollution control at both regional and national levels; noise mapping of cities and execution of potential action plans would be indispensable in reducing the adverse health effect of noise exposure and burden of disease related to environmental noise in India.

5 Challenges Ahead and the Way Forward

Although the concept of noise mapping appears to be very simple and useful, there are various outstanding issues pertaining to noise mapping, dissemination of information to the general public and estimation of population exposure

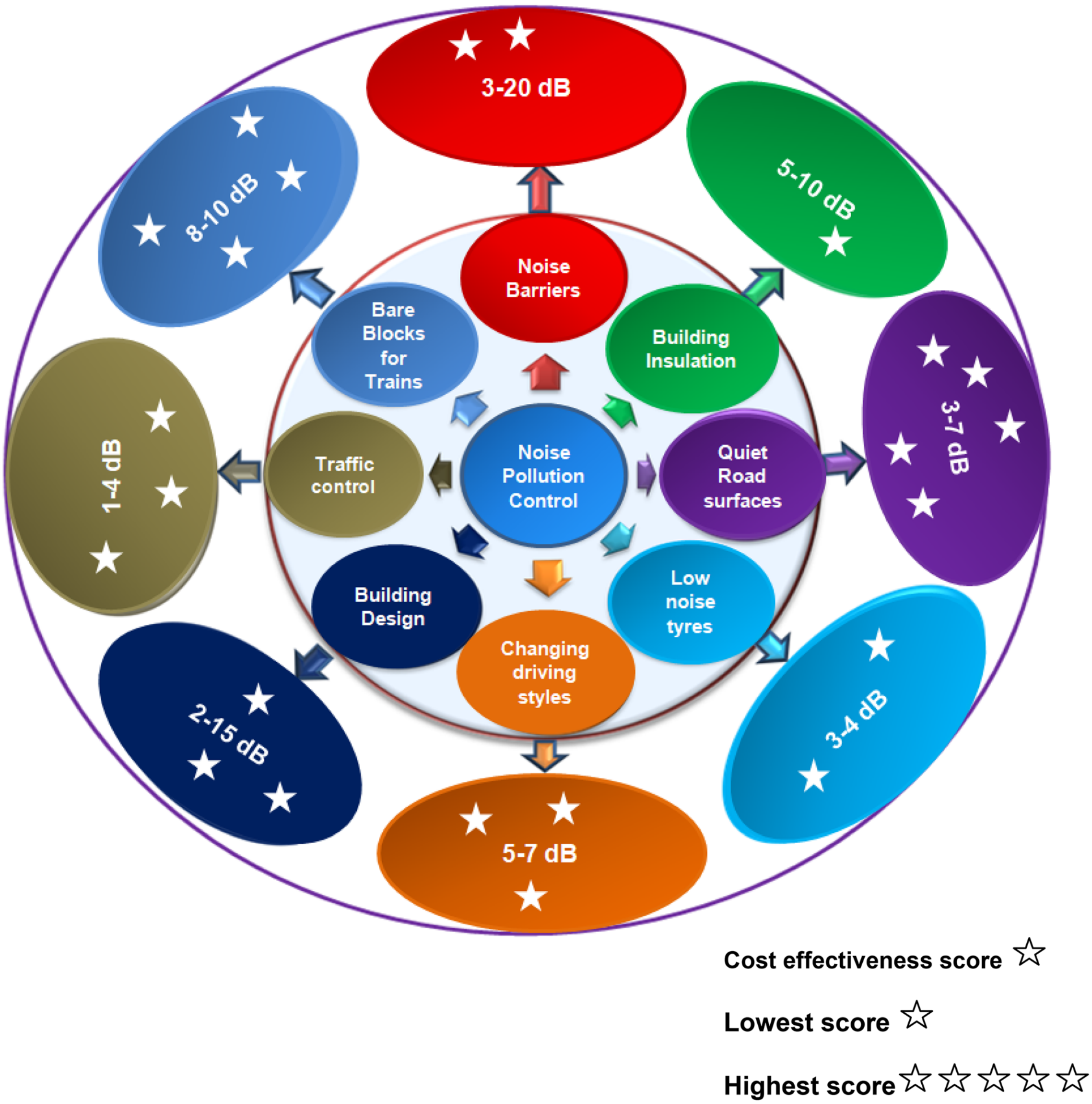

Fig. 6 Cost–benefit analysis of various noise control methods: noise levels reduction and cost-effectiveness score

and noise action planning that makes it sometimes difficult for town planners and pollution control bodies to follow a standardized approach. Figure 7 summarizes the major technical considerations associated with noise mapping in Indian perspectives. The sampling strategy (frequency and number of locations), analysis of ambient noise levels in various seasons, effect of meteorological conditions, use of suitable prediction model and software are some of the crucial issues to be decided prior to undertaking the noise mapping of a city. Eventually, utilizing grid size of 1×1 km in metropolitan cities of India like Delhi with an area of 1500 km^2 approximately invokes at least 800–1000 noise monitoring locations, which is practically cumbersome to cover within a stipulated period of say 1 year. Increasing the grid size to 5×5 km and to 10×10 km will although reduce the number of monitoring locations (or points), but eventually inculcate large uncertainties. Figure 8 shows the various technical attributes and recommended strategy for noise mapping of cities in India. An optimized sampling strategy minimizing the infrastructural requirements, use of validated noise model and appropriate interpolation algorithm and harmonized representation with respect to colour code would standardize the process and eventually lead to minimal uncertainty in the noise predictions. In India, there had been very few studies reported on the noise mapping of a complete city and as such there is no standardized approach recommended so far. A complete standardization in the noise mapping process would essentially entail a harmonized approach with the application of the same noise model and software

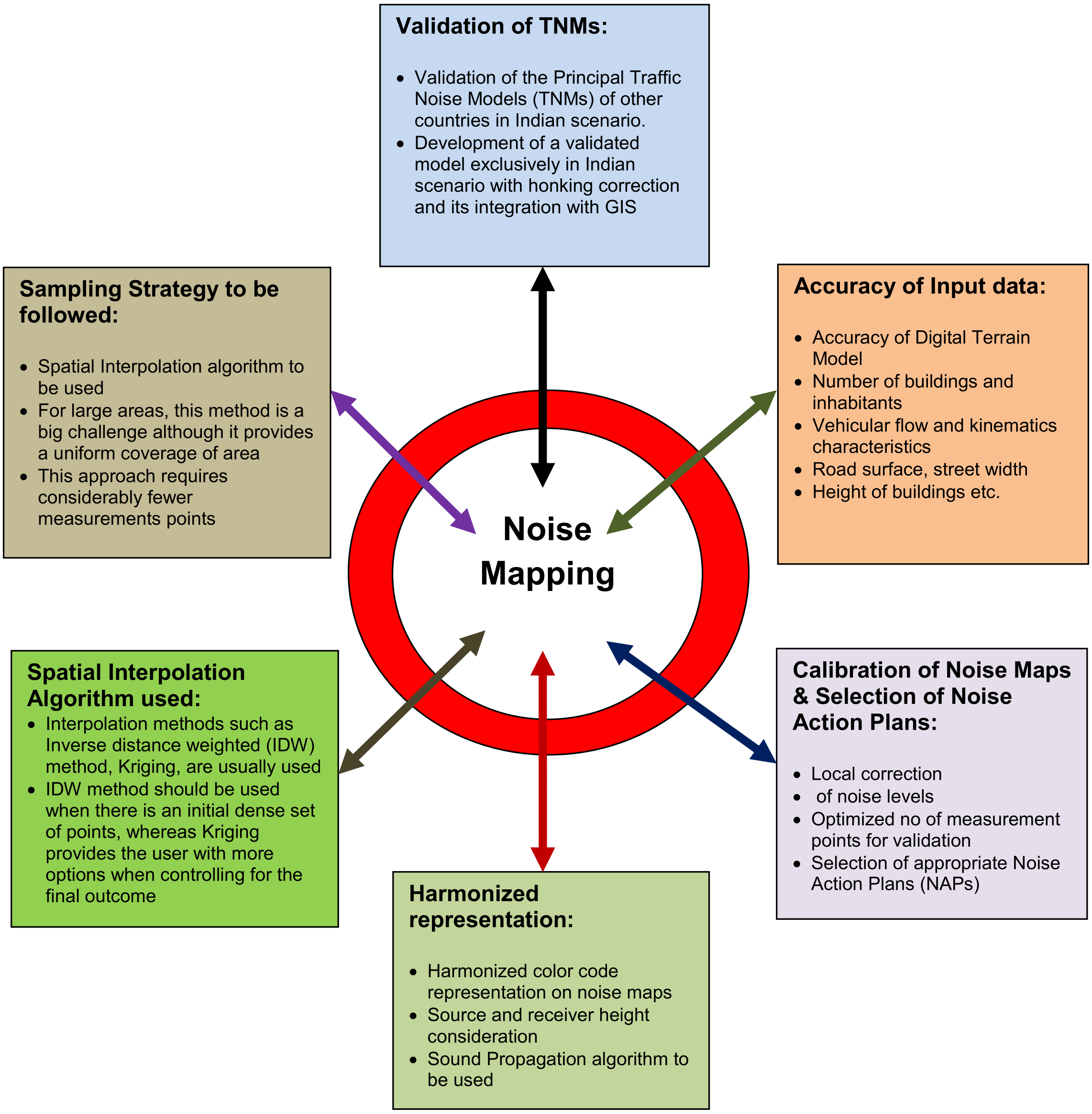

Fig. 7 Major technical considerations associated with noise mapping in India

validated in Indian perspectives Also, certain recommendations are provided based on the standard operating procedures followed internationally and practical experiences as follows:

- Noise monitoring should be carried out as per Noise Pollution (Regulation and Control) Rules, 2000 and amended in 2017. The noise maps should report the ambient day and night equivalent noise levels. Additional sound descriptors such as 24 h equivalent continuous sound level, $L_{Aeq,24h}$ may also be used rather than using the day-night average sound level, L_{dn} or day-evening-night average sound level, L_{den} as recommended in European Noise Directives [77],
- A combined approach involving the use of noise monitoring terminals for noise monitoring of various sites and prediction of ambient noise levels for some points using interpolation algorithms may be exercised. The Noise Monitoring Terminals (NMTs) should be calibrated and traceable to the national standards of sound pressure realized, maintained and disseminated by CSIR-National Physical Laboratory, New Delhi, the National Metrology Institute (NMI) of India for accurate and precise results [78, 79]. It may be noted that use of a single/dual level sound calibrator is a validation procedure only for any noise measuring equipment and not a complete calibration, which has to be done in accordance with the International standard, IEC 61672 (Indian standard, IS

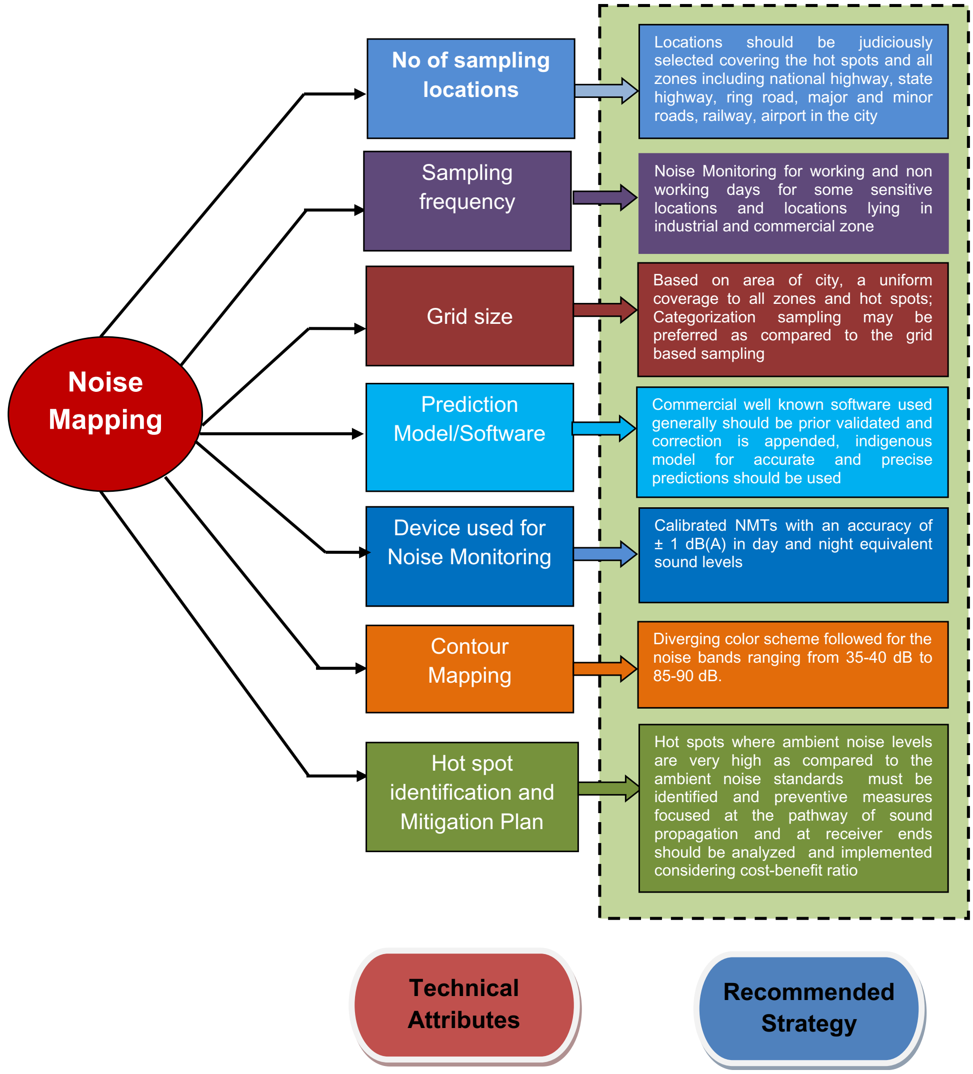

Fig. 8 Technical attributes and suggested strategy for noise mapping of cities in India

15575). Also, the dedicated NMTs employed by various pollution control authorities for continuous noise monitoring throughout the year in many cities of India should be periodically calibrated as per the International standard, IEC 61672.

- A trade-off between the noise monitoring locations and accuracy is to be judiciously analysed prior to executing noise mapping studies as narrowing the grid size improves the accuracy of maps, but at higher costs.
- The sampling of the number of points for mapping the city may be decided on the basis of various aspects such as identification of the sensitive receptors and noise generating sources; dividing the area into suitable hot spots, grid-based sampling; areas of high strategic importance, division of area based on road size/traffic flow/highway road/residential and other zones, etc. Grid-based sampling strategy is cumbersome and incurs large infrastructural costs for noise mapping of larger cities of India. Consequently, a categorization sampling strategy covering the hot spots and all zones uniformly including national highway, state highway, ring road, major and minor roads, railway and airport in the city would be an optimized strategy. Also, in case of the areas lying under the funnel zone of aircraft noise or near to the airports, noise mapping is a must and thus suitable monitoring locations should be identified while conducting the noise maps of the cities in India. It may be noted here that a representative location for all these areas can considerably reduce the number of measurement points so as to save time and money,
- The noise prediction model or software can fill the gap for areas wherein noise monitoring is not conducted. However, the prior calibration of the model or software used would be helpful in minimizing the uncertainty in noise predictions. It is inevitable that a validated model interfaced with GIS must be developed in the next few years that can compensate for noise monitoring for a larger number of sites in metropolitan cities of India.

Consequently, a source emission and propagation model employing the fundamental sound power levels of the various vehicular categories and types and utilization of latest sound propagation modelling algorithms as highlighted in CNOSSOS-EU would serve the purpose [80],

- Average meteorological conditions should be applied instead of favourable conditions as recommended in CEDR report [9],
- A harmonized colour code methodology adopted can be useful for generating comparable and reliable noise maps of different cities of India even if those are developed by different organization or institution or any other stakeholder,
- The cost–benefit or cost-effectiveness analysis for various noise action plans should be clearly identified for accomplishing the desired noise abatement goals [81]. Eventually, a co-ordinated approach involving the various stakeholders such as town planning and developing bodies, pollution control boards, municipal corporations and traffic control units with special budgetary allocations in every financial year would be very fruitful to realize the benefits of noise mapping studies carried out for various cities in India,
- The conventional approach of employing Noise Monitoring Terminals (NMT) for dedicated sites in cities as followed by some pollution control authorities in India may be changed to a mixed approach. For example, one NMT can be employed for noise monitoring of different sites following a predetermined protocol identifying the exact schedule, duration and location for installation, thus following a short-term noise monitoring strategy as highlighted earlier by Garg et al. [82]. Consequently, such an approach shall serve to be a cost-effective approach covering a larger number of sites in a city with a small compromise in accuracy for determination of annual average equivalent day and night noise levels.
- There have been very few studies on noise mapping in airport zones and noise impact due to take-off and landing of aircraft in nearby residential areas in India [83]. The National Building Code of India 2016, part 8, section 4 mentioned that noise emission levels greater than Noise Exposure Forecast, NEF 40 are unacceptable to people, while levels between NEF 25 and 40 may lead to subjective complaints. Levels less than NEF 25 are normally acceptable and no residential development be allowed beyond the NEF 35 level [84]. Thus, future studies focussed on noise mapping in airport zones depicting the noise population exposure would be helpful for the local planning authority for demarcating sensitive zones with special development control regulations and reducing the noise impact of aircraft, especially while undergoing the reversed thrust during landing [85]. In the case of mines, noise mapping had been made mandatory for various places in the mine premises along with personal noise dosimetry of individual workmen exposed to noise level above 85 dB(A) [37]. Although there have been many noise mapping studies [30–32] reported for different regions in India, there is a need of formulation of specific environmental noise policy/legislations in regard to noise mapping in mines like the European Directives [86].

It may be noted that studies on the development of noise maps and identification of noise scenario and hot spots are incomplete and inefficacious without the contemplation, enactment and execution of Noise Action Plans (NAPs). Figure 9 shows the recommended major paradigms of noise mapping and noise action plans that must be followed by laboratories and research institutions, consultants and pollution control bodies. The paradigms are similar to the minimum requirements that action plans must fulfil in European Noise Directives [87]. The action plan should contain estimations in terms of the reduction of the number of people affected by noise and financial information of all the control measures. Cost–benefit analysis of various noise control measures, recommendations of long-term strategy and action plans that must be taken in the next 3–5 years in cooperation with the relevant authorities and all stakeholders and dissemination of the information to general public such as that done by CPCB (http://cpcbnoise.com) must be the major considerations of the noise mapping studies carried out in different parts of the country that would be helpful in fighting the increasing noise pollution in India. Furthermore, a great emphasis and allocation of financial and infrastructural resources and research and development towards the application of noise action planning must be the priority of policymakers, authorities and implementation bodies for reducing the population exposure to excessive ambient noise levels [88]. Also, the prevalence of mixed zones in many areas in metropolitan cities of India makes it difficult to classify them exclusively as silence or residential or commercial zones and makes it imperative to devise noise limits for the mixed category zones consisting of residential apartments, shops and other commercial activities and industries [64, 89] for controlling the noise pollution.

6 Conclusions and Recommendations

The paper presents pros and cons associated with noise mapping in Indian perspectives. It is evident that noise maps are powerful tools for dissemination of information to the public pertaining to noise levels and devising noise control action plans for noise pollution control in urban cities. In Indian perspectives, the National Green Tribunal (NGT), New Delhi orders in 15th March, 2019 have made it inevitable

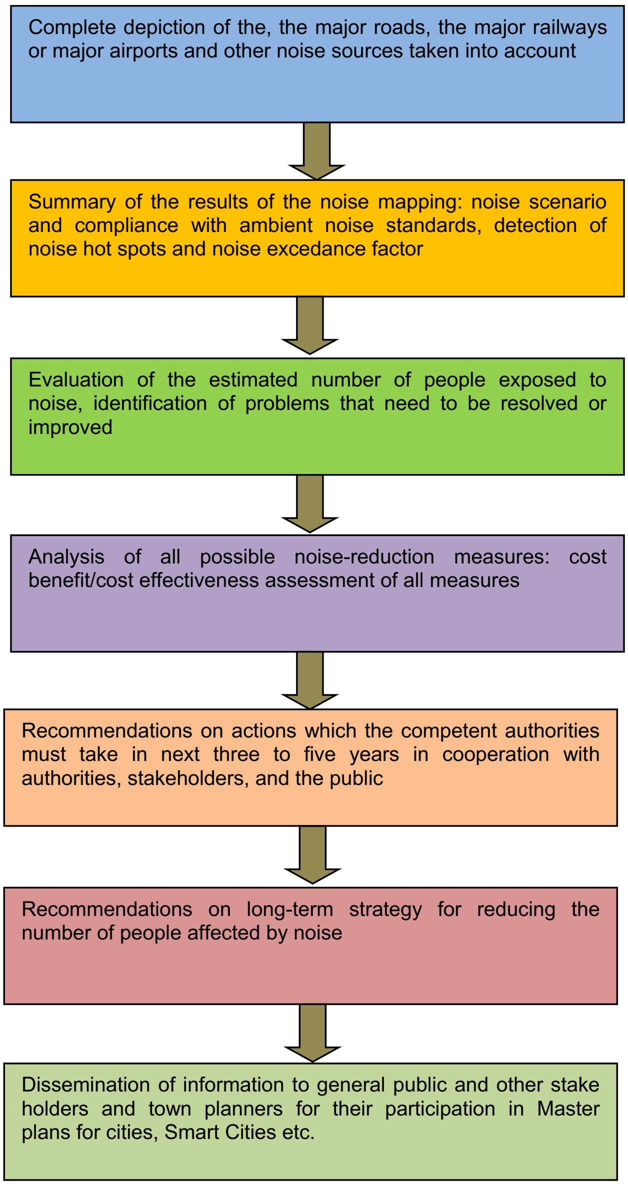

Fig. 9 Recommended major paradigms of noise mapping and noise action plans to be followed by laboratories, academic institutions, consultants and pollution control boards and other stakeholders in India for reducing the ambient noise levels in cities

to develop noise maps, identify the hot spots and execute remedial action plans for controlling the noise pollution in many cities. However, developing the noise maps requires various considerations, for example, sampling strategy, grid size, spatial interpolation algorithm, noise calculation model used and calibration with the actual measurements. The study provides recommendations on various aspects associated with noise mapping in Indian perspectives. However, there are a number of outstanding issues such as selection of number of locations for noise monitoring of a city, sampling frequency to be employed, noise monitoring in different seasons, development of validated noise model, estimation of population exposure, noise action planning and dissemination of information to the general public that need not be focussed for developing accurate and precise maps and sustainable development of acoustic environment in Indian cities. Eventually, as more and more studies are reported in Indian context focussed on noise mapping of the cities and devising noise control action plans, these issues can be resolved and it would provide more clarity and experience to the town planners, consultants, laboratories, research institutions and pollution control bodies in India for conducting the noise mapping studies. A comprehensive strategy majorly focussed on periodic noise monitoring and assessment of noisy hot spots in cities, ascertaining their compliance with respect to the ambient noise standards and devising suitable noise action plans in conjunction with various policy interventions on environmental noise management and control is vital for promoting good health and quality of life. Future studies would comprehensively focus on all these aspects step-by-step after gaining experience from the studies carried out by CSIR-National Physical Laboratory, Delhi on noise mapping of various cities of India. Also, it is envisaged that a national workshop and conference organized in future inviting the participation and experiences of all the stakeholders including laboratories, pollution control boards, academicians and policymakers would facilitate in developing a harmonized directive/standard operating procedure in this regard on noise mapping in India for fighting the noise pollution in the next decades.

Disclaimer The views and opinions expressed in this article are those of authors and do not necessarily reflect the official policy or position of any agency of the Government of India. Although authors have taken utmost care to include models or calculation methods and other information about noise mapping from various sources, however, some error may occur, but not intentionally. The content of the papers is solely to present a retrospective and prospective view and may not be used or considered for disputes redressal in legal framework.

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