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Research article

GIS based spatial noise impact analysis (SNIA) of the broadening of national highway in Sikkim Himalayas: a case study

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Abstract: Mountainous areas create a complex and challenging environment to conduct noise impact analysis of development projects. This paper presents a noise impact analysis methodology using Geographic Information Systems (GIS) and Traffic Noise Model (FHWA TNM 2.5) to portray spatial distribution of noise due to the broadening of the national highway in the mountainous terrain of East Sikkim. Two noise level indices viz., Hourly Equivalent Sound Level (Leq(H)) and Day and Night Average Sound Level (Ldn) were calculated for the year 2004 as pre-project scenario, 2014 as project implementation scenario and 2039 as post-project scenario. The overall trend shows that the proportion of area under adverse noise level decreases from pre-project scenario to project implementation scenario. Over the time the adverse noise impact in the post-project scenario reaches very close to pre-project scenario in case of both the noise indices. Overlay analysis of noise based landuse maps over actual landuse map show that non-compliance of noise based landuse will show similar trend. This trend is mainly attributed to traffic composition and highway broadening induced-traffic volume. The study shows that TNM and spatial interpolation of noise data using Empirical Bayesian Kriging (EBK) are reliable tools to perform noise impact analysis in mountainous areas. Multiple regression analysis show that, radial distance and elevation difference of noise receivers from the nearest point in the highway are significant predictors of Leq(H) and Ldn at lower percentage of heavy trucks in traffic composition.

Keywords: Geographic information systems; traffic noise model (FHWA TNM 2.5); noise pollution; mountain; highway; Kriging; overlay analysis

1. Introduction

Highways are essential for the development and security of a region. It brings prosperity in the form of continuous supply of goods and services, better transport and economic development. However, from the perspective of the environment, broadening of highways create environmental pollution due to increased traffic on the road, landuse change, air and noise pollution, socio-economic changes and loss of biodiversity. Understanding of these environmental impacts is pivotal for unbiased and environmentally appropriate decision making by the government agencies on the viability of such development projects. Environmental Impact Assessment (EIA) is the process of assessing the impacts of such development projects on the environment. EIA involves the assessment of impacts of a development project on the environmental attributes viz. soil resources, water resources, air quality, noise quality, biodiversity, socioeconomy and disaster susceptibility [1,2]. The assessment of noise pollution generated during construction, widening and extension of highways and the consequent rise in traffic is mandatory in such EIA reports. However, conventional EIA is a time consuming and expensive process. It sometimes suffers subjective bias in the assessment of the impacts of a project on the environment [3,4]. Secondly, conventional EIA focuses mainly on the temporal aspect of impact and undermines the importance of spatial distribution of impacts. Finally, mountainous areas due to their innate complexity caused by topography, unpredictable weather and dense vegetation lead to difficulty in data gathering and predicting environmental impacts of a development project. The use of Geographic Information Systems (GIS) overcome the limitation of conventional EIA and provides an unbiased and easily interpretable EIA [5]. GIS is a computer based system for capturing, storing, querying, analysing and displaying geographically referred data [6]. GIS based Spatial Noise Impact Analysis (SNIA) can portray the spatial and temporal distribution of noise quality in a terrain. It can be done by using traffic noise simulation model and spatial tools of GIS. Conventional statistical methods like regression analysis can be applied for further interpretation of the results.

Noise pollution is a pertinent adverse impact of highway traffic. It has been found to be highest near the highway areas [7]. Effective Roadless Volume (EFV) is a spatial indicator to measure the landscape penetration by roads and the related impact due to traffic noise. Noise level has been found to be the highest near urban areas and places with high vehicular traffic noise [8]. Traffic noise causes several physiological and psychological damages to human health, like annoyance and aggression, hypertension, high stress level, hearing loss, sleep disturbance, interference with speech [1,9-11]. Bus and heavy truck traffic have been found to contribute most to noise induced annoyance [53]. Schulz (1978), Passchier-Vermeer and Passchier (2000) and Stansfeld and Matheson (2003), provide in depth reviews on the health effects of automobile induced noise pollution [12-14]. Traffic noise causes ecological impacts like, change in animal behaviour, their spatial distribution, anti-predator behaviour, reproductive success, foraging behaviour, population density and community structure [15-18]. Traffic noise has also been found to cause depreciation of property value [19].

The widely used traffic noise simulation models are the Calculation of Road Traffic Noise (CORTN) developed by the UK and the US based Federal Highway Administration’s Traffic Noise Model (FHWA TNM) of Version 2.5. These models have been integrated with GIS software, like TNoiseGIS the commercial software, to generate automatic noise emission values for any number of receptor points and can generate soundscape of the noise affected area [20]. FHWA TNM 2.5 and CORTN compute noise level based on a series of adjustments to a reference sound level considering traffic flow, distance and shielding effect composition, road gradient, road surface, distance and barriers [21-23]. FHWA TNM 2.5 has been widely used for prediction of noise in the EIA for highway projects [5,24,25]. FHWA TNM 2.5 and GIS have been used to construct noise maps for a highway broadening project in West Bengal [5]. FHWA TNM 2.5 has been used in association with GIS in a number of studies to prepare noise maps in urban environments [26-29]. Along with GIS independent models like FHWA TNM and CORTN, GIS integrated models like SPreAD-GIS has been developed. SPreAD-GIS is an ArcGIS toolbox developed for traffic noise model made especially for wilderness areas [30]. Construction of noise maps has become very relevant to see the regions that are affected by noise and to put forward the future pollution mitigation approaches [31].

Preparation of GIS based noise impact analysis involve spatial data collection like Global Positioning System (GPS) readings, Digital Elevation Model (DEM), satellite and areal imageries for mapping of vegetation areas, buildings, houses and other noise barriers, receivers and roads. Ancillary data like traffic volume, composition, speed and ambient noise level at various locations are required along the roadway as inputs for noise models [27]. Spatial analysis of noise analysis include spatial interpolation for predicting noise level in the un-sampled space of the study area. The spatial interpolation methods include, Kriging, Inverse Distance Weighting (IDW), Triangulated Irregular Network (TIN) and Nearest Neighbour Method [32-35]. Empirical Bayesian Kriging (EBK) is a robust and straightforward spatial interpolation technique. Unlike Ordinary kriging, which relies on spatial homogeneity, EBK considers uncertainty in spatial parameters. Moreover, it works better than Ordinary kriging in spatial prediction, when the sample size is small ($n < 60$). The algorithm behind EBK generates several semivariogram models to minimize the prediction error generated from the uncertainty of model parameters. Each semivariogram gets a weight based on Bayes’ rule, which predicts how likely the observed data can be generated from a semivariogram [36-39].

Studies on noise impact analysis in mountainous areas show that, traffic increases during dry seasons. Relative humidity and up-hill movement of traffic also increase noise level in mountainous areas [40]. Moreover, close proximity of the residences to the roadway in mountainous areas expose the residents to higher levels of traffic noise [41]. Banerjee and Ghose (2016), provides a comprehensive review on the aspects of spatial EIA in mountainous highways and the role of geospatial analysis methods in such studies [42]. It is observed that, majority of traffic induced spatial noise impact analysis (SNIA) are confined to urban areas with simple terrain undermining the need of SNIA in mountainous areas. If we consider the case of Sikkim, which is situated in the North-Eastern Himalaya, it is undergoing rapid economic transformation to accommodate its huge potential in the tourism industry [43,44]. Moreover, being a border state it has significant military presence. Under these circumstances, widening of highway in Sikkim Himalaya is essential to fuel fast economic development and meet its military needs. But, how does such a highway project influence the distribution and magnitude of traffic induced noise pollution in mountainous areas? How does such noise pollution ultimately affect the rural communities, wildlife and forest ecosystem in the spatial and temporal scale? How effective are the traffic noise models in predicting noise level in mountainous areas? What are the environmental factors that mostly influence the performance of the models? All these pertinent questions have spatial dimension and require geospatial analysis.

In this paper an attempt has been made to apply the techniques of GIS to perform a SNIA of broadening of the national highway NH 31A (renamed as NH 10) in the East district of Sikkim. The highlighting features of the paper are:

- FHWA TNM 2.5 has been used to calculate Hourly Equivalent Sound Level (Leq(H)) and Day-Night Average Sound Level (Ldn) in the study area. Ambient noise level from three locations in the study area has been used to validate the calculation using Normalised Mean Square Error (NMSE). Geoprocessing techniques, viz. Buffering and EBK interpolation have been used in ArcGIS environment for the preparation of thematic maps of noise level indices for pre-project, project-implementation and post-project year scenarios. Root Mean Square (RMS) and Standardised RMS have been used for the crossvalidation of spatial interpolation of known points. Reclassification of noise index maps were done using landuse based Central Pollution Control Board (CPCB) ambient noise level category. All the maps show initial decline, followed by recovery of noise level from pre-project to post-project scenario. Overlay of noise index based landuse maps on actual landuse map of year 2006 show that there is initial decline, followed by rise in non-compliance of noise based landuse from pre-project to post-project scenario.

- Multiple regression analysis of noise level indices were done, considering Leq(H) and Ldn as dependent variables and radial distance and elevation difference of receivers from highway as predictor variables. Radial distance and elevation difference of receivers from highway were found to be significant predictors of Ldn and Leq(H) at low percentage of heavy trucks in traffic composition.

2. Method

2.1. Study area

The study area stretches from Rangpo (27^{o}10’31.26”N, 88^{o}31’44.43”E, Elevation 300 m) to Ranipool (27^{o}17’28.74”N, 88^{o}35’31.11”E, Elevation 847 m) in the East district of Sikkim, a stretch of 27 km. The noise impact area or study area is a buffer area of 2 km radius from the National Highway, NH 31A (renamed as NH 10) (Figure 4). This highway is the lifeline for the people living in Sikkim. It is the main route which connects Sikkim with the rest of India, provides defence and civil supplies and promotes economy mainly in the form of tourism. In 2008–2009, under the supervision of the Ministry of Road Transport and Highway (MoRTH), Government of India and Border Roads Organisation (BRO), the broadening of NH 31A has commenced to promote defence and economic growth in Sikkim. The highway will be broadened from its present width of 7 m to 12 m. This broadening of highway will cause increase in traffic volume, as projected in Table 4. The project stretches from Sevok in West Bengal to North Sikkim. The road corridor chosen for the study is relatively much smaller than the actual stretch of the highway. The reason for choosing this small corridor is due to its relatively homogenous geography and moreover, it is the most affected area in the East district due to the highway broadening project. The study area has steep elevation which is predominated by subtropical vegetation, interspersed by small human habitations, traditional farming areas and towns like Rangpo, Singtam and Ranipool. The highway closely follows river Teesta (Figure 1, 2 and 3). It is worth noting that, Sikkim falls under biodiversity hotspot of North-Eastern Hills of Himalaya and it is home to a large number of endemic species [45]. So unabated noise pollution can severely affect the sanctity of the wildlife and ecosystem in this area.

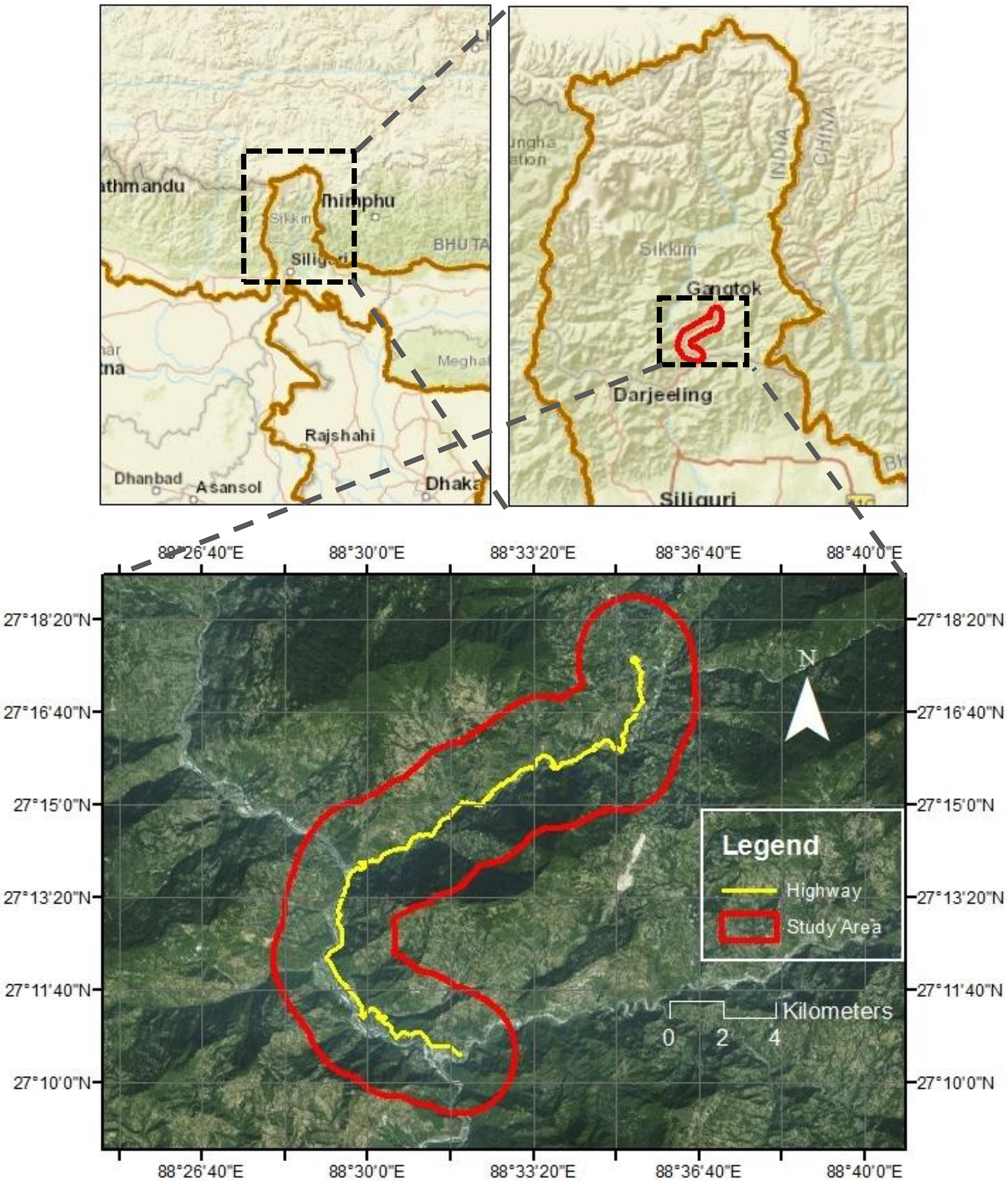

Figure 1. Image of the study area (Courtesy: ESRI).

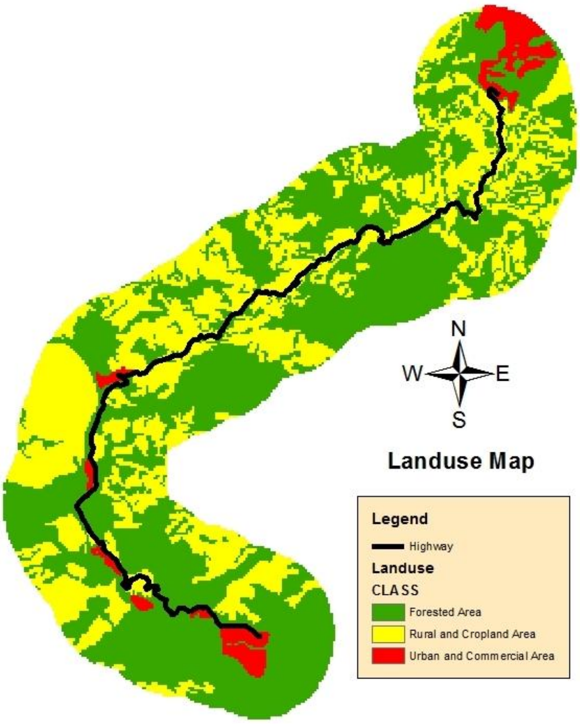

Figure 2. Landuse map of the study area.

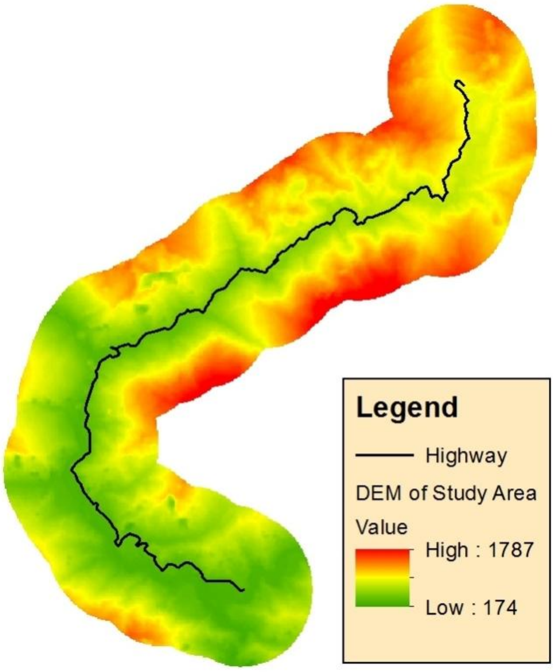

Figure 3. DEM of the Study Area (elevation value is in meter unit). Courtesy: bhuvan.nrsc.gov.in.

Figure 4. Images of National Highway NH 31A (renamed NH 10). A: Large part of the road is in the midst of the forest. B: The road cuts through steep elevations. C: Human habitations are in close proximity to the road. D: Frequent turns is a common feature of the road. E: Sound receivers at a distance from the road. F: The road closely follows river Ranikhola and Teesta. G: Road elevation changes from place to place. H: Broadening of the road has exposed many steep slopes of the mountain. (Photographs taken on 16/10/2016).

2.2. Government policies on noise pollution

Highway projects and tarred roads in Himalaya and forest areas require environmental clearance by the Environmental Impact Assessment Notification, 1994, Govt. of India [46]. Unfortunately, in case of border states of India (like Sikkim) new highway projects and highway expansion projects do not need scoping during EIA, leaving enough legislative gap to degrade the environment at the cost of highway development [47]. This is mainly for national security reasons. Highways have been identified as a potential source of noise pollution by the Ministry of Environment, Forests and Climate Change (MoEF), Government of India, and it is mandatory to conduct noise impact analysis for EIA of highway projects. While measuring noise level, a 24 hour of monitoring is to be done with special emphasis on covering sensitive environmental receptors like thickly populated areas, hospitals, schools, wildlife corridors etc. CPCB noise standards (Table 1) should be followed to designate various landuses viz., Industrial zone, Commercial zone, Residential zone and Silent zone as per the Noise Pollution (Regulation and Control) Rules 2000 [48].

Table 1. Ambient noise standard*.

Area Code	Category of area	Limits in dB(A) Leq		Landuse Code for the present study
		Day time**	Night time***	
A	Industrial area	75	70	4
B	Commercial area	65	55	3
C	Residential area	55	45	2
D	Silence zone****	50	40	1

Source: * CPCB (2000).

** Day time reckoned in between 6:00 a.m. to 9:00 p.m.

*** Night time reckoned in between 9:00 p.m. and 6:00 a.m.

****Silence zone is defined as an area comprising not less than 100 metres around hospitals, educational institutions and courts. The silence zones are zones which are declared as such by the competent authority.

Although, the Act acknowledges the adverse impact of noise pollution on wildlife and natural ecosystem, it does not exclusively designate forest areas as silent zone. This leaves a scope where the competent authority (like the State Pollution Control Board) can afford not to consider forest areas as silent zone eventually affecting the sanctity of nature and wildlife. Studies show that noise level in natural forest areas should not exceed 45 dB [30,49-51]. In this study, forest areas have been considered as silent zone due to their ecological relevance.

2.3. Noise index and description of FHWA TNM 2.5 model

It is one of the most popular computer based traffic noise measurement model and it is recommended by MoEF for EIA of highway projects. It provides options to calculate Leq(H) (Hourly A-Weighted Equivalent Sound Level), Ldn (Day-Night Average Sound Level) and Lden (Community Noise Equivalent Level, where "den" stands for day/evening/night). Leq(H) is used to describe the receivers cumulative noise exposure from all events over an hour period. It is widely used for measurement of non-residential landuse. It is expressed as:

$$Leq(H) = 10log_{10}[Total\ sound\ energy\ during\ one\ hour] - 35.6 \quad (1)$$

where, the constant, 35.6 is subtracted to convert the sound index into a time average value. Ldn on the other hand, measures the cumulative noise exposure from all events over a full 24 hours, with events between 10 pm and 7 pm, increased by 10 dB to account for greater sensitivity to noise during night time. It is appropriate for cumulative noise impact for residential landuse. It is expressed as:

$$Ldn = 10log_{10}[Total\ sound\ level\ during\ 24\ hours] - 49.4 \tag{2}$$

where, 49.4 is subtracted from the index to convert it into a time average like value. Leq(H) and Ldn covers the noise impacts on the ecological and community aspects of the highway broadening. These noise indices depend upon the number of transit event, loudness and duration of noise exposure to the receivers [52]. TNM algorithm performs a series of adjustments to the basic noise level called *Reference Sound Level* of a stream of vehicles by considering a number of factors, described in Equation (3) and Equation (4):

$$Leq = L_0 + \Delta L_i \tag{3}$$

and,

$$\Delta L_i = A_{VS} + A_D + A_B + A_F + A_G + A_S \tag{4}$$

where, Leq: hourly equivalent sound level; L_0: reference energy mean emission level; A_{VS}: volume and speed correction; A_D: distance correction; A_B: barrier correction; A_F: flow correction; A_G: gradient correction; A_S: ground cover correction. The total Leq(H) is given by Equation 3:

$$Total\ Leq = 10log \sum_{i=1}^{n} 10^{Leq(i)} \tag{5}$$

where, $Leq(i)$ is the Leq(H) of *i-th* vehicle type and *n* is the total number of types of vehicles. The vehicle types accepted by TNM are automobiles, medium trucks, heavy trucks, buses and motorcycles [5,22,53,54].

For the present study, three time frames were considered viz. year 2004 as pre-project scenario, 2014 as project implementation scenario and 2039 as post-project year scenario. In the *pre-project scenario*, the highway width is 7 meter and road pavement is made up of non-bitumen emulsion of 300 mm thickness. On the other hand, in *project implementation scenario* the highway width is 12 meter and road pavement is made up of bitumen emulsion of 580 mm thickness. The *post-project year* has same road condition as project scenario, except that the traffic volume has increased. The details of traffic composition for various years is given in Table 2. Traffic composition of year 2004 was provided by MoRTH, while it was calculated in case of 2014 and 2039 using annual growth rates of traffic as provided by BRO (Table 3). Various inputs for TNM was prepared as mentioned in Table 4. High resolution images of the study area were downloaded from Google Earth and georeferenced from geographic projection system of GCS-WGS-1984 to plane projection system of WGS-1984-UTM-Zone-45N. The georeferenced images were merged to a single high resolution image of the study area. It was used to prepare point feature shapefiles of building rows, receivers, road geometry. LISS III satellite image and merged high resolution image of the study area together were used to prepare the point feature shapefile for tree zone. DEM was used to extract elevation value for the point features in the shapefiles. A sum total of 872 receivers were created in ArcGIS environment as point feature shapefiles, which included villages, towns, isolated houses and randomly selected points in the study area. The point feature shapefiles prepared in ArcGIS were exported as dbase files and converted to excel files. Prerequisite arrangements were made in FHWA

TNM 2.5 data input interface to accommodate inputs from excel files. This was followed by error check and finally calculation of Leq(H) and Ldn. Equation 3 and 4 were used in FHWA TNM 2.5 to calculate Leq(H) and Ldn considering all other factors to be constant except A_{VS} , which contributes to the traffic volume and speed correction of the model. Reliability assessment of the model was done by comparing observed noise level with the predicted noise level at appropriate locations within the study area. The FHWA TNM 2.5 noise index output of three locations in the study area were compared with ambient noise level provided by Sikkim State Pollution Control Board (SPCB) using *Normalised Mean Square Error* (NMRE) method [61]. It is an estimator of the overall deviations between predicted and measured values, as given in Equation 4.

$$NMSE = \frac{1}{n}\sum_{i=1}^{n}\frac{(P_i - M_i)^2}{\bar{P}\bar{M}} \tag{6}$$

where, $\bar{P} = \frac{1}{n}\sum_{i=1}^{n} P_i$, $\bar{M} = \frac{1}{n}\sum_{i=1}^{n} M_i$, P_i is the predicted value in the *i-th* location and M_i is the measured value in the *i-th* location. The performance of a model is considered acceptable if, NMSE < 0.5. To perform spatial analysis of noise indices, Output data tables generated from FHWA TNM 2.5 were exported as comma-delimited ASCII file and converted to excel files. The output excel files were imported in ArcGIS for spatial analysis.

Table 2. Traffic composition and volume.

Category of Vehicles	Pre-Project Year (2004)	Project implementation Year (2014)	Post-project Year (2039)
	Average Peak Hourly Traffic		
Automobiles	30	221	1292
Medium Truck	9	58	201
Heavy Trucks	10	0	2
Buses	13	5	20
	Annual Average Daily Traffic		
AADT	1496	4968	24174

Table 3. Annual growth rates (in percent) for traffic*.

Vehicle type	Year		
	2010–2015	2015–2020	2020 and beyond
Automobiles	6.41	7.03	7.79
Medium Truck	4.32	4.74	5.24
Heavy Trucks	4.32	4.74	5.24
Buses	4.89	5.37	5.93

Courtesy: *BRO, Border Roads Organization

Table 4. Data types, source and processing method for TNM input.

Data type	Data source	Data Processing
Vehicle inputs		
Vehicle type	BRO*	Direct input
Traffic volume (vehicle per hour)	BRO, MoRTH**	Direct input
Traffic speed (km per hour)	BRO	Direct input
Road inputs		
Road coordinates	Google Earth***, DEM****	Georeferencing, Image merging, vectorization
Road width	Field study, BRO	Direct input
Pavement type	BRO	Direct input
Receiver inputs		
Receiver coordinate	Google Earth, DEM	Georeferencing, Image merging, vectorization
Receiver height	Field study	Averaging
Building inputs		
Building row coordinate	Google Earth	Georeferencing, Image merging, vectorization
Building row height	Field study	Averaging
Building percentage	Field study	Averaging
Tree inputs		
Tree zone coordinates	Google Earth, LISS III*****, DEM	Georeferencing, Image merging, vectorization
Average tree height	Field study	Averaging

Courtesy: *BRO, Traffic data of NH 31 A (nearest town, Rangpo) collected from 29/06/2012 to 06/07/2012 by Border Roads Organization, Govt. of India.

**MoRTH, Traffic data of NH 31A (nearest town, Singtam) collected on July 2004 and December 2004 by Ministry of Road Transport and Highways, Govt. of India. Downloaded from http://morth.nic.in/writereaddata/sublinkimages/sikkim2987772247.htm accessed on 18/05/2014

***Google Earth image data accessed during 10/05/2011 to 21/03/2012

****DEM accessed from http://bhuvan.nrsc.gov.in/data/download/index.php under CartoDEM- all versions as CARTOSAT-1 satellite image on 11/04/2012

*****LISS III accessed from http://bhuvan.nrsc.gov.in/data/download/index.php under Resourcesat-I sattelite image on 18/12/2014

2.4. Spatial analysis of noise impacts

Thematic maps of Leq(H) and Ldn for year 2004, 2014 and 2039 were prepared by converting imported excel files into point feature shapefiles. Spatial interpolation of noise receivers were done using EBK, Ordinary Kriging and IDW methods as *known points*. The raster images thus generated were crossvalidated using Geostatistical Analysis Wizard of ArcGIS and interpolation method with the best result was accepted for further analysis. *Crossvalidation* is the method used to assess the quality of spatial model made from the interpolation method. It involves, comparison of the interpolation method by repeatedly removing a known point from the data set, predicting its value by using remaining known points and interpolation method, and finally calculating the prediction error by comparing the estimated value from the known value of the given point. The two common diagnostic statistics used for this are, *Root Mean Square* (RMS):

$$RMS = \left(\frac{1}{n}\sum_{i=1}^{n}\left(z_{i,act} - z_{i,est}\right)^2\right)^{1/2} \tag{7}$$

and standardised RMS:

$$Standardised\ RMS = \left(\frac{1}{n}\sum_{i=1}^{n}\frac{\left(z_{i,act} - z_{i,est}\right)^2}{s^2}\right)^{1/2} = \frac{RMS}{s} \tag{8}$$

where, n is the number of points, $z_{i,act}$ is the known value of the point i, $z_{i,est}$ is the estimated value of the point i, s^2 is the variance and s is the standard error. An interpolation with small RMS and standardised RMS close to value 1 is considered as a good interpolation [6,55].

A buffer area of 2 km radius from the highway was constructed as the study area. The choice of noise impact buffer radius depends on factors viz., ecological sensitivity; number, size and proximity of human habitation and complexity of the terrain. Selection of the buffer radius for the present study was based on the experts' opinion on the extent of propagation of traffic noise due to the highway broadening [5,56]. Thematic maps of noise level indices were cropped using the buffer and reclassified based on impact category, as shown in Table 5. The impact category is based upon CPCB noise standards based landuse classification (Table 1). To assess the impact of traffic induced noise pollution on the landuse of the study area, landuse map was prepared using interactive supervised image classification tool in ArcGIS by processing IRS-P6 LISS-III[1] image of 26/06/2006 downloaded from *bhuvan.nrsc.gov.in*. The landuse raster image was reclassified into urban and commercial area, rural and cropland area and silent zone area. Change in the landuse between year 2004 and 2014 were compared in Bhuvan online spatial database. Only a marginal change in the landuse was observed. Thereby, no landuse change was assumed for the convenience of the impact analysis. The noise indices based landuse reclassified raster images were overlayed on the landuse map of the study area of year 2006 using Raster Calculator based on the overlay condition:

$$Output\ raster = \left[\begin{pmatrix} landuse\ code\ of\ noise\ index \\ based\ reclassified\ map \end{pmatrix} > \begin{pmatrix} landuse\ code\ of\ landuse \\ map\ of\ year\ 2006 \end{pmatrix}\right]$$

The output rasters were binary maps showing areas which complied or violated landuse norms as stated in Table 1.

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[1] IRS-P6, is Indian Remote-Sensing Satellite series of Indian Space Research Organization (ISRO) with onboard sensor named LISS III (Linear Imaging Self-Scanning Sensor-III). It is also known as ResourceSat-1.

Table 5. Impact category based on Noise level range.

Noise Range in dB(A)	Impact category	Landuse code
Less than 45 dB	No impact (NI)	1
45–65 dB	Slight adverse impact (SAI)	2
65–85 dB	Moderate adverse impact (MAI)	3
More than 85 dB	High adverse impact (HAI)	4

2.5. Multivariable regression analysis

To assess whether any significant dependence exist between noise level indices and environmental attributes in mountainous areas, a regression analysis was done in SPSS environment. Proximity analysis was done in ArcGIS to measure the *radial distance* of the receivers from the nearest point of the highway point shapefile. Similarly, DEM was used to calculate the *elevation difference* between receivers and the nearest point of the highway point shapefile. The noise level for various years at respective receivers was tabulated with radial distance and elevation difference in excel file. The table was transferred to SPSS environment for multiple regression analysis. Noise level indices, Leq(H) and Ldn for year 2004, 2014 and 2039 were regressed using predictor variables viz. radial distance of noise receiver and elevation difference between noise receiver and nearest point of highway.

2.6. Overall methodology of the spatial noise impact analysis

Initial stage of the study involved preparation of spatial and ancillary database. Spatial database of the model include the X, Y and elevation coordinates of road geometry and spatial objects like tree zone, building rows and receivers. This was done using high resolution satellite images and ArcGIS tools viz., merging, georeferencing and vectorization of data. Ancillary database included details of traffic volume, composition and speed at various road geometry points. The spatial and ancillary database was used to feed inputs for FHWA TNM 2.5. The outputs of FHWA TNM 2.5 were used for post-model geoprocessing in the form of EBK interpolation and preparation of noise index thematic maps. This was followed by map reclassification and overlay analysis to assess spatial distribution of noise impacts and extent of violation of noise based landuse. Temporal resolution of the year 2004, 2014 and 2039 was used to analyse the temporal variation in the noise impact over the study area. Multiple regression analysis was included in SNIA to analyse any possible relationship between radial distance and elevation difference of the receivers from the highway to noise level at the receiver point in a complex terrain like mountainous area. An overall methodology of the spatial noise impact analysis is given in Figure 5.

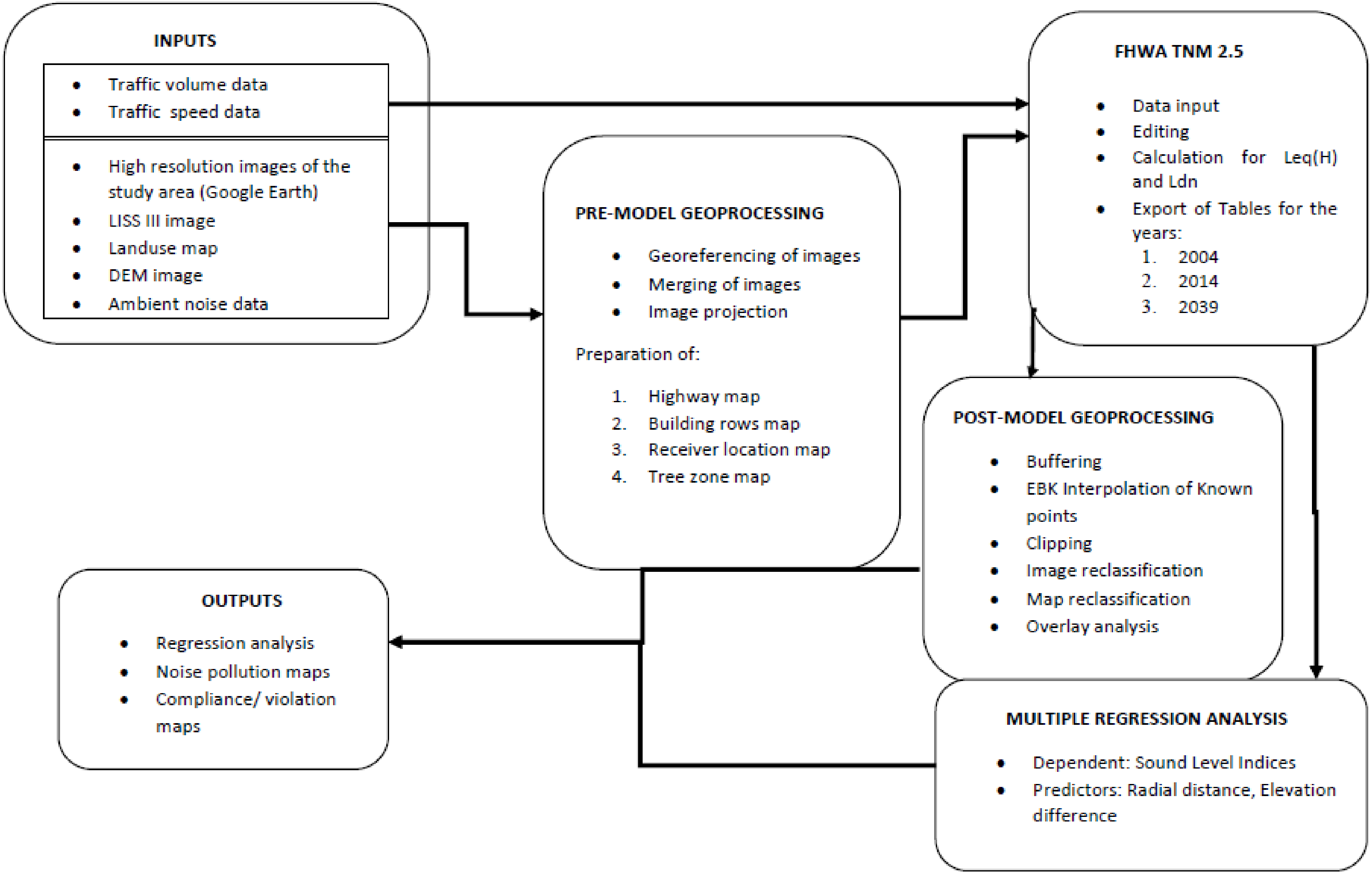

Figure 5. Illustration of methodology of Spatial Noise Impact Analysis Model.

3. Results and Discussion

3.1. Spatial analysis of noise level indices

Thematic maps of noise level indices were prepared by interpolating known points and delimiting the extent of the interpolated surface by intersecting the study area with the interpolated surface. Cross-validation test of RMS and standardised RMS showed that EBK had the lowest values and values closest to 1 respectively, as compared to Ordinary Kriging and IDW. This shows that EBK is comparatively a more reliable interpolation than the other two interpolation methods (Table 6). The TNM generated noise level was compared with pre- and post- monsoon data of ambient noise level from three locations in the study area (Table 7). The NMSE calculated from Table 7 was 0.076 (<0.5). Thereby, the noise level prediction of TNM was reasonably well within the ambient day and night noise interval.

Table 6. Cross validation result of Empirical Bayesian Kriging.

Map Name	Root Mean Square	Standardized Root Mean Square
Leq(H) 2004	9.171	0.972
Leq(H) 2014	9.071	0.965
Leq(H) 2039	9.160	0.962
Ldn 2004	5.965	0.996
Ldn 2014	6.024	0.980
Ldn 2039	6.029	0.995

Table 7. Comparison of observed and modelled noise levels.

Location	Date of Monitoring*	Time of Monitoring	Observed Noise levels in dB(A)		Averaged Observed Noise levels in dB(A)			Modelled Noise levels in dB(A) as Leq (h) (P_i)
			Day**	Night***	Day	Night	Day–Night Average value (M_i)	
Ranipool	13/03/14	Day and Night	66.4	53.6	67.3	53	60.15	36.9
	08/12/14	Day and Night	68.2	52.4				
Middle Camp	03/03/14	Day and Night	65.4	60.3	64.95	59.45	62.20	49.6
	16/09/14	Day and Night	64.5	58.6				
Bageykhola	16/01/15	Day and Night	71	61	69	62.5	65.75	62.8
	11/09/13	Day and Night	67	62.5				
Average							$\bar{P} = 62.70$	$\bar{M} = 49.767$

Courtesy: * State Pollution Control Board, pre- and post- monsoon data

** Day time reckoned in between 6:00 a.m. to 9:00 p.m.

*** Night time reckoned in between 9:00 p.m. and 6:00 a.m.

Figure 6 and 7, show the spatial distribution of impacts of highway broadening under various noise level indices. The figures show that, the fraction of adverse noise impact is higher in pre-project scenario and in post-project scenario as compared to project-implementation scenario. This is mainly due to the presence of heavy trucks (16.13%) in the year 2004, which contribute to the highest amount to the higher frequency noise level (≥2000 Hz) [22]. On the contrary, the proportion of heavy trucks fall to mere 0.176% in 2014. Although, the Average Peak Hour Traffic progressively increases from 2004 to 2039 (Table 2), the contribution of heavy traffic show a decreasing trend. By 2039, the contribution of heavy trucks fall to 0.132%, but the overall Average Peak Hour Traffic increases from 62 in 2004 to 1515 in 2039. This rise in traffic substitutes the noise generated from heavy trucks in 2004. These observations are in harmony with the studies done [7,8,12]. This change in traffic composition is attributed mainly to the shift of Sikkim's economy towards tourism based industry which heavily depends on passenger buses and taxis. A similar trend is observed in case of Ldn also. In both the cases of Leq(H) and Ldn, there is slightly higher impacts of noise pollution in 2004 as compared to 2039, but a substantial drop in noise pollution in 2014. Partly, the credit of this decline in noise pollution goes to drop in heavy trucks in the traffic composition and partly is described by the broadening of the highway which reduces traffic congestion. Hence, it can be observed that the broadening of the highway will be initially beneficial in mitigating noise pollution in the study area. However, with rise in traffic volume, the noise pollution level will return close to its pre-project scenario by 2039. Secondly, it is observed that, the noise impact tapers off as we move away from the centreline of the highway as discussed in the multiple regression analysis. This trend is observed in both Leq(H) and Ldn maps as we move from year 2004 to 2039 (Figure 6, 7 and 8). The immediate consequence of this trend will be on the distribution of landuse in terms of noise level. Figure 9 and 10, show the spatial distribution of areas where noise level exceed the landuse based noise level as stated in Table 1. On comparing the landuse map (Figure 2) with Compliance/Violation maps (Figure 9, 10 and 11), it is observed that, rural-cropland areas and forested areas will be adversely affected by the noise pollution.

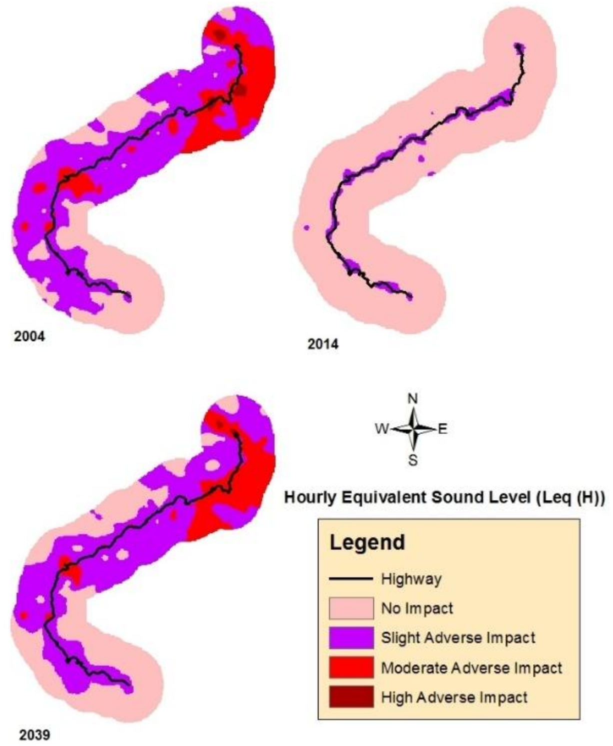

Figure 6. Spatial Distribution of Hourly Equivalent Sound Level (Leq (H)) in the study area.

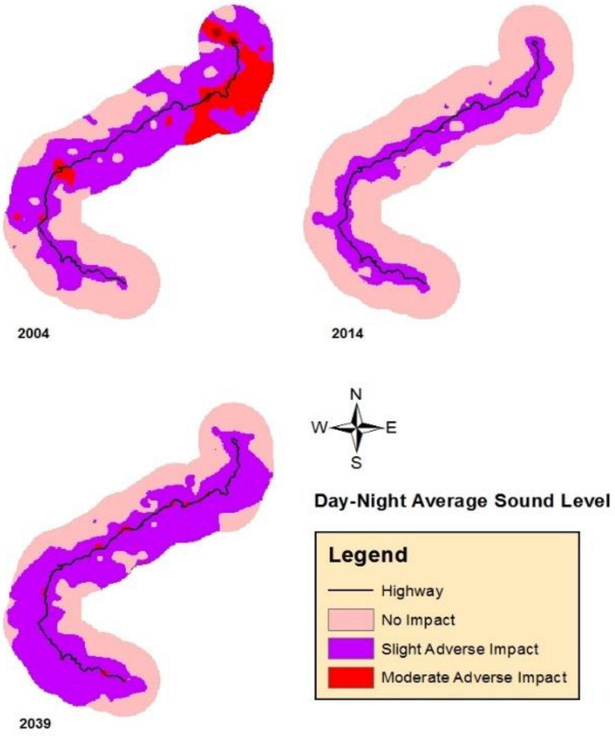

Figure 7. Spatial Distribution of Day and Night Average Sound Level (Ldn) in the study area.

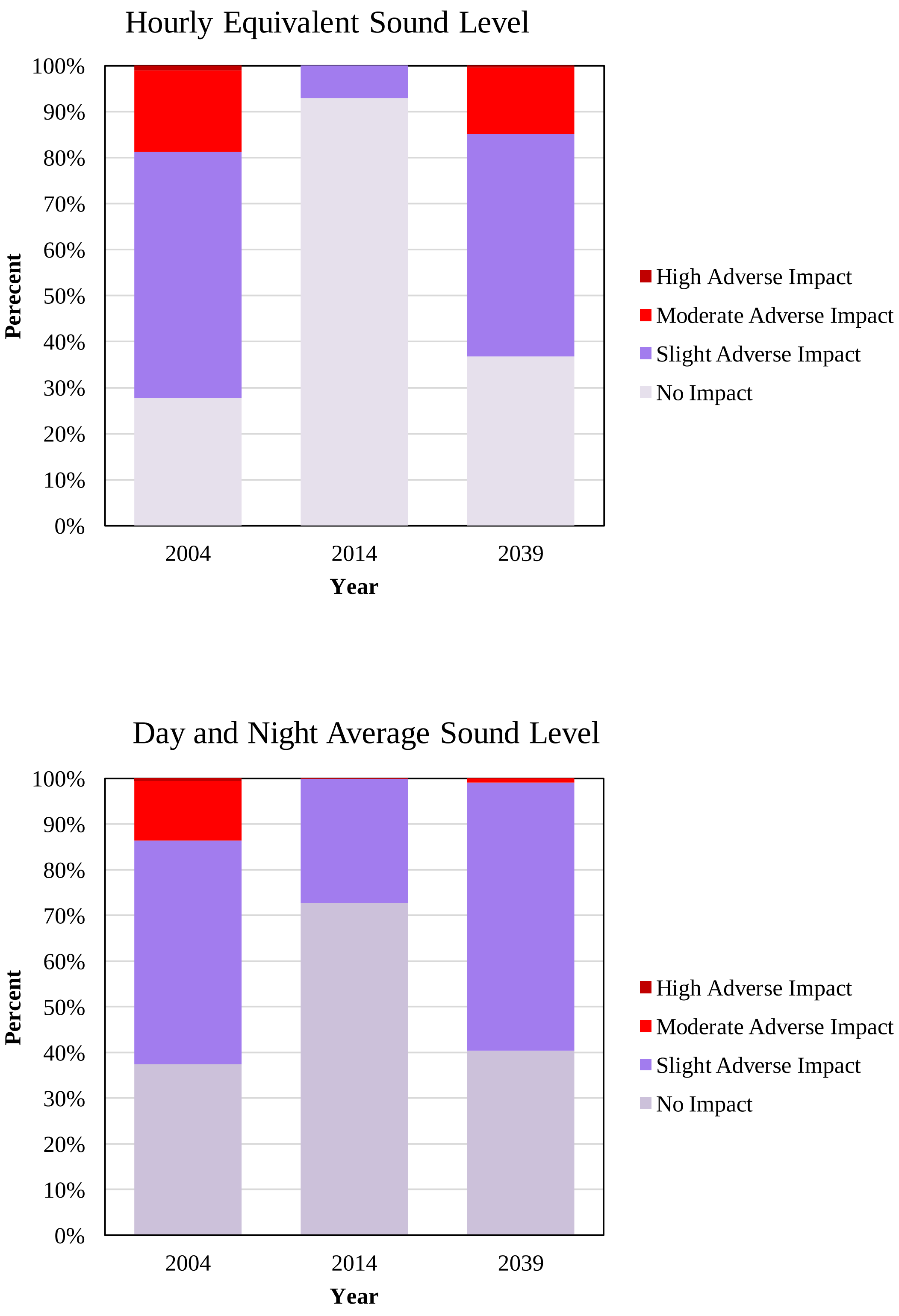

Figure 8. Percent wise distribution of area under various noise impact category. Total study area is 98.375 km^2.

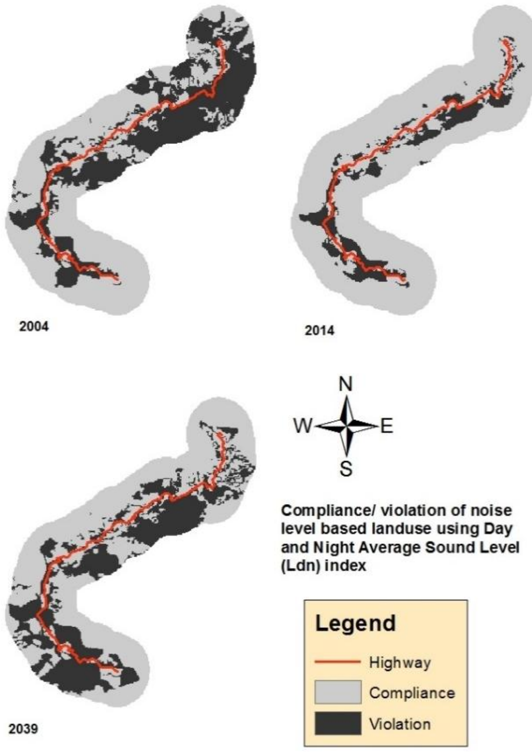

Figure 9. Binary maps on compliance or violation of noise level based landuse for Ldn noise index.

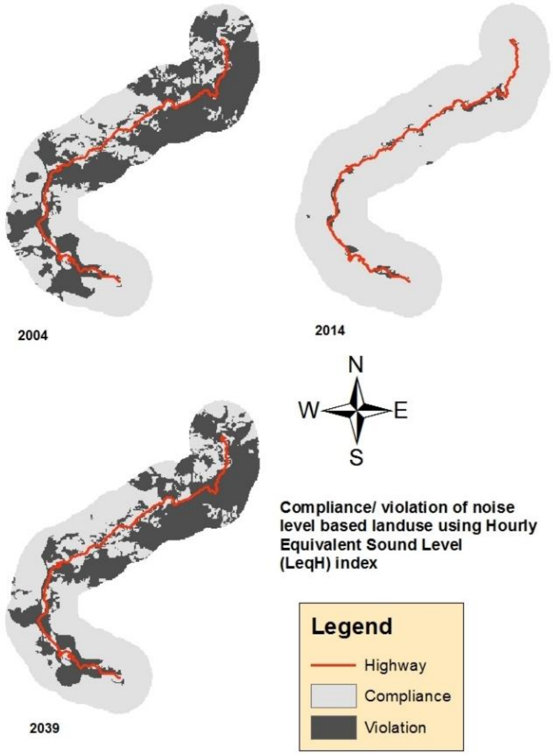

Figure 10. Binary maps on compliance or violation of noise level based landuse for Leq(H) noise index.

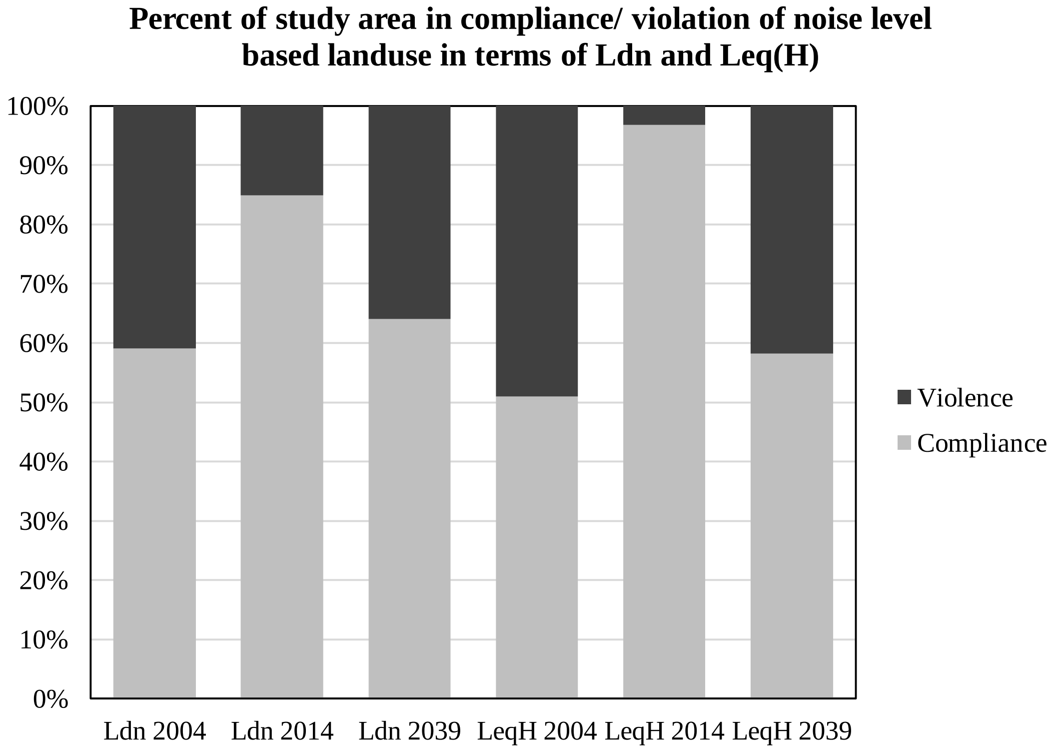

Figure 11. Percent wise distribution of area under compliance or violation of noise level based landuse. Total study area is 98.375 km^2.

3.2. Multiple regression analysis

Figure 6 and 7 show that, the fraction of adverse noise impact decrease with increase in radial distance. Secondly, on comparison of Figure 3 with Figure 6 and 7, it is observed that, the fraction of adverse noise impact is more pronounced in flat valley areas as compared to areas with greater elevation, as the steep slope with vegetation cover act as a natural noise barrier. Some of these observations were statistically analysed. The analysis show that there is significant dependency of Leq(2014), Ldn 2014 and Ldn 2039 with radial distance and elevation difference of the receivers from the highway. On the contrary, Leq(H) 2039 and Ldn 2004 can be moderately explained, while Leq(2004) is poorly explained by radial distance and elevation difference of the receivers from the highway. On comparing Table 8 and Table 9, it is inferred that, the presence of heavy trucks in the traffic composition greatly increases the residual part in the regression model. The unexplained or residual part of the regression model can be due to traffic composition, vegetation cover, barriers and building rows. The inter-correlation of radial distance and elevation difference was found to be high at 0.759. However, collinearity statistics viz. Tolerance and Variance Inflation Factor (VIF) were found to be 0.423 and 2.362 respectively for all predictor variables. Hence, no significant collinearity was found between the predictor variables in all regression models of Ldn [57-60].

Table 8. Means, standard deviation and intercorrelations for sound indices and predictor variables (N = 872).

Variable	Mean (in dB)	Std. Deviation (in m)	Intercorrelation	
			Distance	Elevation
Leq(H) 2004	54.612	16.814	−0.306	−0.127
Leq(H) 2014	34.918	11.145	−0.712	−0.436
Leq(H) 2039	51.521	15.481	−0.408	−0.218
Ldn 2004	51.463	16.065	−0.375	−0.188
Ldn 2014	42.236	11.150	−0.711	−0.436
Ldn 2039	49.108	11.149	−0.711	−0.436
Predictors (in m)				
Distance	785.424	584.312	1	0.759
Elevation	226.381	247.296	0.759	1

Table 9. Simultaneous Multiple Regression Analysis summary for sound level indices, Distance from road and elevation difference between road and receiver (N = 872).

Model	Variable		B	SEB	β	R^2	F (2, 869)	$P < 0.05$
	Type	Name						
1	Dependent	Leq(H) 2004	61.967	0.900		0.12	59.180	0.000
	Predictors	Distance	−0.014	0.001	−0.496			
		Elevation	0.017	0.003	0.249			
2	Dependent	Leq(H) 2014	45.867	0.435		0.Seto2	493.321	0.000
	Predictors	Distance	−0.017	0.001	−0.898			
		Elevation	0.011	0.002	0.245			
3	Dependent	Leq(H) 2039	60.363	0.797		0.186	99.528	0.000
	Predictors	Distance	−0.015	0.001	−0.573			
		Elevation	0.014	0.003	0.217			
4	Dependent	Ldn 2004	59.954	0.839		0.163	84.653	0.000
	Predictors	Distance	−0.015	0.001	−0.549			
		Elevation	0.015	0.003	0.229			
5	Dependent	Ldn 2014	53.183	0.436		0.531	492.425	0.000
	Predictors	Distance	−0.017	0.001	−0.897			
		Elevation	0.011	0.002	0.245			
6	Dependent	Ldn 2039	60.054	0.436		0.531	492.516	0.000
	Predictors	Distance	−0.017	0.001	−0.897			
		Elevation	0.011	0.002	0.245			

Note: B is the Regression Coefficient, SEB is the Standard Error of B, β is the Standardised Coefficient, R^2 is the Coefficient of multiple determination, F is the F- test score and P is the significance level.

4. Conclusion

The study presents a GIS based methodology for performing Spatial Noise Impact Analysis of transport related projects in remote locations with difficult terrains such as mountainous areas. It shows that, GIS based spatial analysis in association with FHWA TNM 2.5 model is a good traffic noise prediction model for mountainous areas. Secondly, it reveals that Empirical Bayesian Kriging coupled with crossvalidation test is a reliable GIS method for spatial prediction of noise level over a complex terrain. The impact analysis show that, the spatial distribution of adverse noise level was high in pre-project scenario (2004), low in project-implementation scenario (2014) and again high in post-project year (2039). Comparison of landuse map with noise impact maps show that rural and forested areas will be adversely affected by increase in heavy trucks in the traffic composition and increase in traffic volume due to broadening of highway. Statistical analysis show that radial distance and elevation difference of noise receivers from the highway are good predictors of Leq(H) and Ldn at traffic compositions with low number of heavy trucks. The methodology used in the study can be used as a reference for similar studies in such landscapes in future.

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Conflict of interest

No potential conflict of interest was reported by the authors.

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