An Evaluation of Spatial and Temporal Acoustical Patterns of Roadway Traffic through GIS Techniques

Mohammed Raza Mehdi, Mudassar Hassan Arsalan
Institute of Geographical Information Systems
National University of Sciences and Technology, Islamabad, Pakistan
razamehdi@yahoo.com

Abstract

Most of the environmental tribulations is embedded in a spatial matrix. Such location disparities in environmental quality resulting from the patterns of transportation and land use are legitimate themes of transportation engineering, environmental management and geographic inquiry. In this context, the empirical data of mega cities of developing countries could help in tracing the relationship between relevant urban, environmental and transportation factors. Several populous cities of the developing world are currently facing the issue of environmental degradation. For instance, Karachi, the largest city of Pakistan is growing at the rate of 4.2 percent per annum [1](UNEP, 1999) where the vehicular noise and blowing of horns have increased alarmingly and is up to 30 to 35 dB (A) above the internationally accepted tolerable thresholds [2](Mehdi, 2002). Periodic monitoring is the only solution to assess the spatial as well as temporal variations of noise pollution within the city. The growing trends and levels of successful implementation of environmental laws could only be ascertained thereafter. Geo-informatics enables scientists, engineers and decision makers to monitor, model and predict the spatio-temporal acoustical data. However, this functional link is missing in many developing countries due to lesser comprehension of 'Geo-informatics' and inadequate financial resources. In this research paper, a methodological study has been presented for exploring spatio-temporal variations of traffic induced noise through the analytical tools available in state of the art Geo-informatics, in view of a city of a developing country. Generating real world acoustic data, georeferencing, transformation into Geographical Information System (GIS) and finally construction of mesogeographic thematic maps has been the procedural steps. Sampling methods, spatio-temporal modeling procedures and interpretation of resultant maps are the key areas of discussion. It is anticipated that similar concept can be applied in other parts of the developing world.

Key words: GIS, Noise Pollution, Traffic

Introduction

The impacts of rapid urbanization include settlements, traffic congestion, noise pollution and associated diseases [1](UNEP, 1999). There is no question that noise is both a public health hazard and an environmental pollutant as well. Road traffic noise results from the collective contribution of the noise produced by individual vehicle. The vehicular noise is itself a product of several auto-parts. [3]Priede (1980) established the principal sources of engine noise. Engine noise is due to fuel combustion and due to the mechanical impacts. The different sources in an engine and their internal mechanism were discussed by [4]Challen and Croker (1982).

Karachi, the largest city of Pakistan, is growing at 4.2 per cent per annum [1](UNEP, 1999). In Karachi, the blowing of horns increased alarmingly and is up to 30 to 35 dB(A) above the tolerance limits [5](SEPA, 1994). The most noticeable sources of noise pollution in Karachi, are the auto rickshaws, trail motorbikes and the fag horns of public transport [6](Zaidi, 1990). The local administration has time and again attempted to impose a ban on the use of defective silencers and pressure horns [7](Correspondent daily Dawn, 1999). Previous studies have attributed vehicular noise pollution to large scale migration, increase in the numbers the number of vehicles [8](ESCAP, 1990), traffic jams, defective roads, defective vehicles, and above all the human factor which in our society is reflected by inherent impatience under social pressures giving rise to such acts as blowing of horns unnecessarily (*e.g.* [9]Shaikh and Rizvi, 1990; [5]SEPA, 1994; [10]Mehdi *et al.*, 2002).

Materials and data

The most recent large-scale (n=78) noise level data monitored in Karachi was of 1993 [5](SEPA, 1994). [10]Mehdi *et al.* (2002) had spotted noise risk zones (NRZs) through GIS with this limited data. The levels have changed significantly during the last decade and there is a need to explore the present ground realities with a greater sample size (*e.g.* n > 200).

Noise is not continuous and normally distributed phenomenon in between its peak and lowest values. In other words Noise intensity level changes rapidly within seconds. Therefore average (mean) was not representative for that skewed distributed variable. Average value is highly affected from extremes for instance during five minutes highest value is 100 dB(A) and lowest value 55 dB(A), which shows 78 as an average. Hence the people have to bear higher than 85 dB(A) mostly. To overcome this factor, mode (most repetitive value) has been chosen.

Corresponding Author: Mohammed Raza Mehdi
NUST Publishing, © (2008), ISSN: 2070-9900

It was practically possible to record mode Noise levels, since the synchronization time of the digital instrument was less than a second. These Noise intensity levels were monitored in two ways:

1. **Mode** of five minutes at 4-5 meter from the source and 4 - 41/2 feet above the surface
2. **Peak** of five minutes at 4-5 meter from the source and 4 - 41/2 feet above the surface

Noise meter

Sound Level measurements are in general, carried out through Electro acoustic methods in which the Noise is converted to an electrical signal by a microphone and subsequently amplified electronically prior to some form of analysis. The sound level meters are the basic portable instruments used for the measurement of continuous Noise. They comprise essentially a microphone to pick up the sound, an electronic amplifier, and one or more frequency-weighing network and a meter to display the level of sound. They are produced to meet various international standards, which define the important aspects of their specifications.

Monitoring sites' sampling

Continuous noise monitoring is usually preferred for estimating the level of pollution because these data provide the best representation. In a developing country, such as Pakistan, this requires resources beyond the reach of the investigators. However, a database has been designed on the basis of primary field data collection. This database has comprehensive spatial and temporal coverage.

Coverage on micro scale throughout Karachi was the huge and difficult task especially owing to number of financial and human resource constraints. Despite these limitations, more than 300-site sample-size was targeted and successfully covered in this study. When the sites studied are plotted on a map according to their geographical positions, it automatically forms the shape of metropolitan Karachi. Sampling was performed on following criteria:

- Potential of noise pollution
- Spatial coverage
- Target neighboring parameter such as near source, not in open grounds etc.

Methodology

It has been estimated that over eighty percent of the world's data have a spatial component ([11]Worrall, 1991; [12]MIC, 1999). Noise pollution is amongst them containing rigorous relationship with geo-spheres. Spatio-temporal analyses of this kind of variables do not only show the distributions, patterns and variations with respect to time but also assert to find out the reasons of these variations. Every phenomenon that have relation with earth, are spatially organized and be full of interaction with other spatially distributed objects / factors. Some times the study of those factors provides clues about the main studied objective owing to their spatial associations.

Development of continuous spatial patterns

There are many situations where the available observations are insufficient to explore the spatial patterns in an area satisfactorily [13] (Bernhardsen, 2002). In GIS analysis, 'Interpolation' is the procedure of predicting the most likely value of the new point based on available observations ([14]Journel and Huijbregts, 1978; [15]Clark, 1979; [16]Mousset-Jones, 1980; [17]Brooker, 1991; [18]Geron *et al.*, 1994). Interpolation is used to convert data from point observations to continuous surface so that the spatial patterns sampled by these measurements can be compared with the patterns of other spatial entities. Spatially monitored data do not cover the domain of interest continuously (*i.e.* they are samples). Interpolation can be performed through miscellaneous statistical techniques in which Inverse Distance Weighted (IDW) interpolation is commonly used in environmental GIS

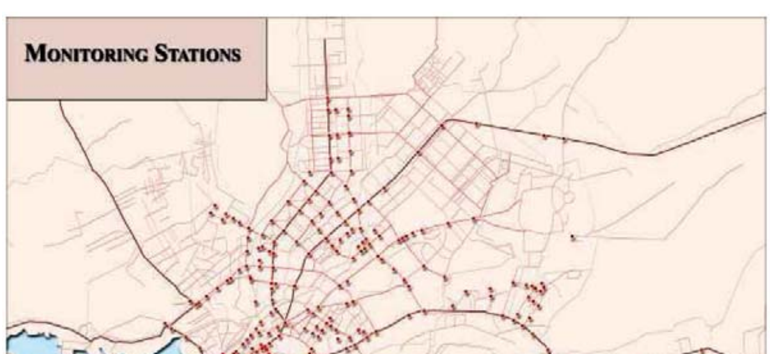
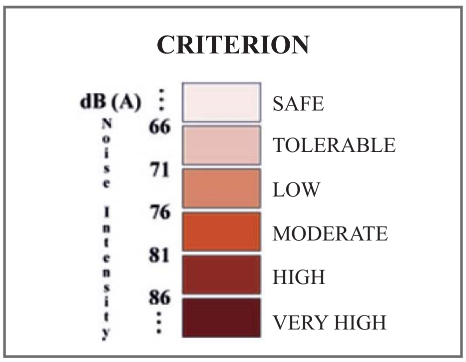


Fig. 1. Sampling stations for more measurement

modeling ([19]Isaaks and Srivastava, 1989; [20]Deutsch and Journel, 1992; [21]Arsalan, 2000; [10]Mehdi *et al.*, 2002) to create raster / grid overlays from point data.

In this analysis, grid themes have been constructed for each set of samples in first step by completing appropriate values of required parameters under the ArcView Spatial Analyst environment. In second step, interpolated grid has been reclassified according to the criterion given below. For the purpose of demarcating the spatial patterns of pollution, safe to very high-noise zones were spelled out for Karachi. A thorough literature review has provided insight for formulating the following criterion:



Temporal variations

Time is one of the controlling factors of every dynamic phenomenon in this world. Noise generates and propagates with variety of speed depending upon the nature of the source and medium. That speed reveals the rate of dynamism with respect to time. It is difficult to monitor continuously (spatially) to some extent especially when spatial canvas is huge and with quite enough details. On such, scale time-to-time variation may be recommended to scrutinize with respect to morning, afternoon, evening or low to high peak times [22](Arsalan, 2002). GIS may provide spatio-temporal analysis functions that depict temporal variations as well as spatial variations at a time through different modes**.**

One of the themes, which have been developed for temporal variation, is the use of algebraic grid. Map algebra is a high-level computational language for performing cartographic spatial analysis using girded (raster) data. It provides a way to create mathematical and statistical operations that compare grid themes [14](Bernhardsen, 2002). In this regard collected data has been converted into interpolated grids for mornings, afternoons and evenings of working and weekend / off days. Finally standard deviation has been calculated to identify the variation of noise pollution during the week.

Discussion

The maps produced depicting the spatio-temporal patterns of noise pollution across the Karachi metropolis are listed in Table I. Each resultant map is followed by discussion of in-situ variations at micro geographic level.

Table 1. Spatio-Temporal Variations of Noise Levels Across Karachi Metropolis

Parameter / Variations	Figure No.
1. Working Day Mornings	
Peak	2
Mode	3
2. Working Day Afternoons	
Peak	4
Mode	5
3. Working Day Evenings	
Peak	6
Mode	7
4. Weekend Mornings	
Peak	8
Mode	9
5.Weekend Afternoons	

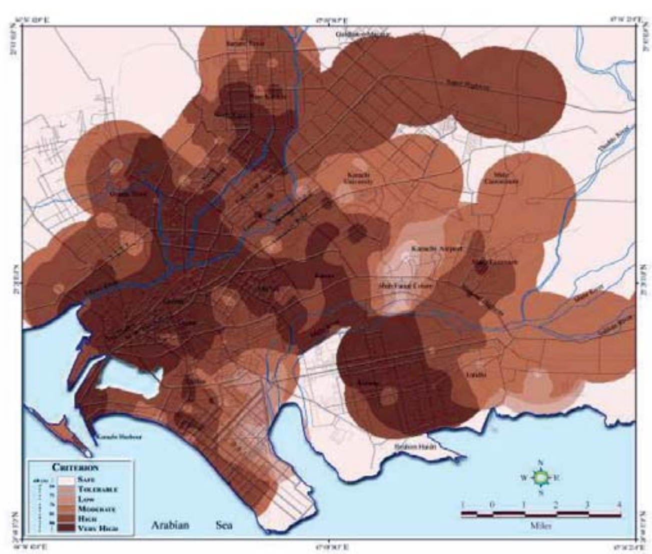


Fig. 2. Working day mornings: Peak

Parameter / Variations	Figure No.
Peak	10
Mode	11
6. Weekend Evenings	
Peak	12
Mode	13
7. Weekly Average	
Mode	14
Peak	15
Total (Combined Mode and Peak)	16

While performing the surface interpolation for this map (Fig. 2) in ArcView, the boundaries of the maximum diffusion were inadvertently not taken care of. Morning trips in Karachi are mostly school and work related. Locations of SITE, Orangi Town, Gulistan-e-Johar & DHA are in moderate noise zone; rest of the city is within the high noise, whereas the core old city and major intersections of district Karachi Central are under very high noise. *Noise islands* identified in Fig. 2 are the major wholesale and commercial areas, *i.e,* core of Karachi city, Lasbela, Grumandir, vicinity of National Stadium, Qaidabad, Liaquat market Malir, Suhrab Goth and Nagan Chowrangi.

In Fig. 3 the undeveloped parts of housing schemes and DHA are safe while most of the city is under moderate noise. The core old city and vicinities of M. A. Jinnah Road are under high noise extending up to Nazimabad. The *noise islands* are areally wide covering old city (core) area, Malir and Nagan Chowrangi. Unlike some western mega-city dwellers, the Karachiites are not early birds, which is manifested in this figure.

Monday to Thursday afternoons are occupied with work and other activity trips. The traffic and narrow roadway width produce congestion. In this figure the large areas are surrounded by very high-noise zone. Remarkably, high and very-high noise zones influence the city. The

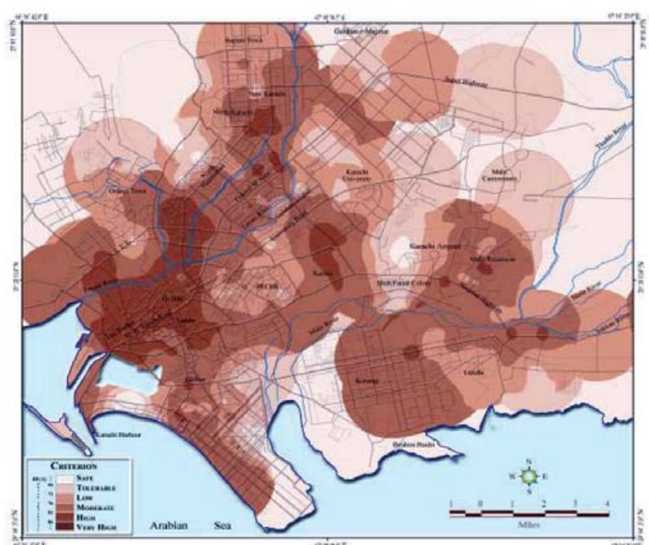


Fig. 3. Working day mornings: Mode

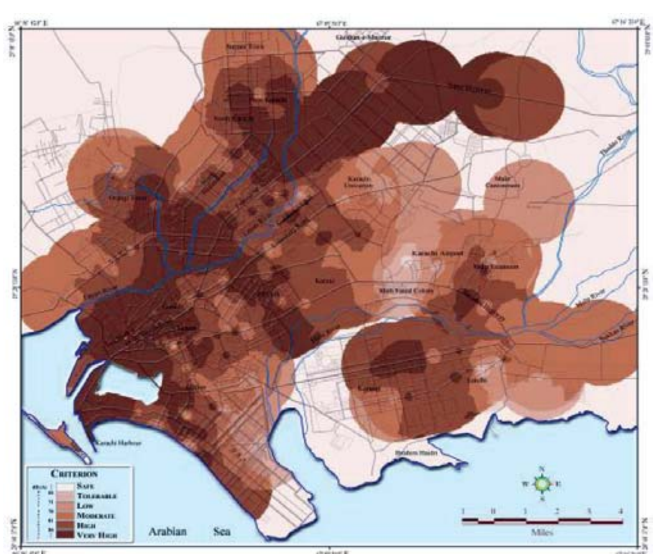


Fig. 3. Working day mornings: Mode

patterns formed help in understanding the traffic and trip trends of the city and answer the inquiry at micro geographic scale. Two major *noise islands* could be observed in the Fig. 4. The first one encompasses the whole old city (core) of Karachi and elongates up to densely populated areas of Liaquatabad and Golimar. A large part of district Karachi Central (former) becomes *noise island* during this period of time.

Fig. 5 has to be understood vis-à-vis its counter part for mornings. There are clear spatial contractions and the moderate noise zone has nucleated around the core old city and stretched out to localities where traffic manoeuvring is difficult due to geometric and space limitations. Overall the city remains under low and tolerable limits of noise. For this temporal variation only a small *noise island* can be seen around the Nazimabad Chowrangi.

The scenario is overwhelmed by the high and very-high noise zones comparable to weekends. As the activities on Monday to Thursday are more than the three other days, the spatial patterns show agglomeration of high and very high-noise clusters. Fig. 6 confirms that the peak hours of activities and traffic in Karachi Metropolis are between 6:00 p.m. and 11.00 p.m. At this temporal juncture the recorded noise has created several spatially large *noise islands* all over the city, evident on the map.

The trend of high noise zone seems to be shifting (Fig. 7) from old city towards district Karachi Central. The districts West, Malir, East and partially south are in the moderate noise zone. The most populous district of Pakistan, *i.e,* Karachi Central, although a planned and relatively younger locality is under high noise due to higher rate of vehicle ownership and urbanization. Even the modal readings of noise seem to be affecting the densely populated areas at this temporal juncture. The *noise islands* formed are around the intersections of district Karachi Central.

The peak noise levels recorded during weekend mornings, were mostly the horns blown by transit vehicles and likewise. Hence, whenever the peak behaviour of noise is portrayed, the difference of weekend and working day

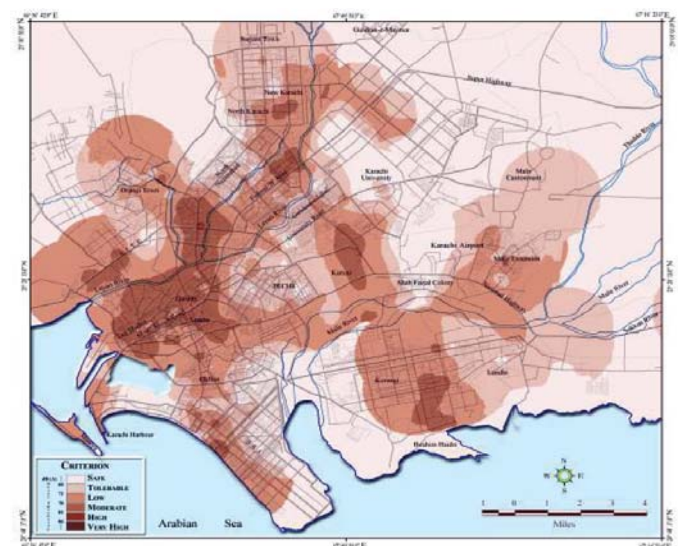


Fig. 5. Working day afternoons: Mode

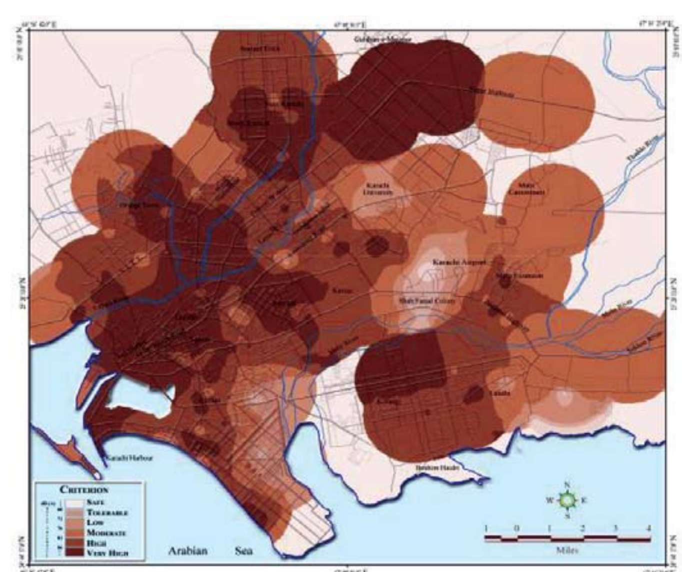


Fig. 6. Working day evenings: Peak

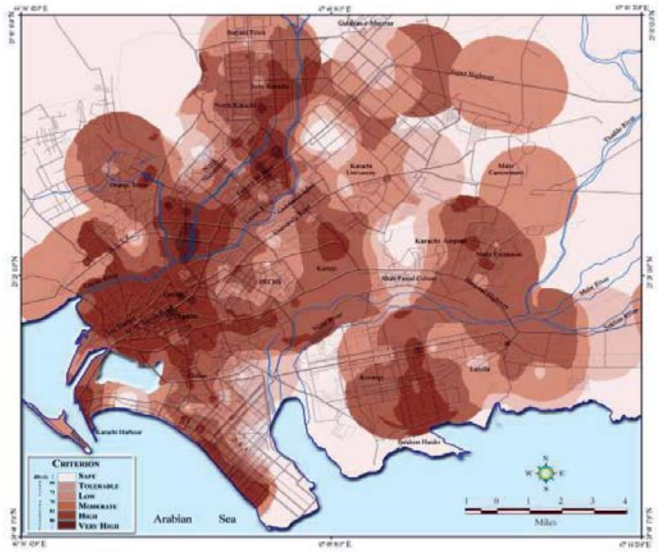


Fig. 7. Working day evenings: Mode

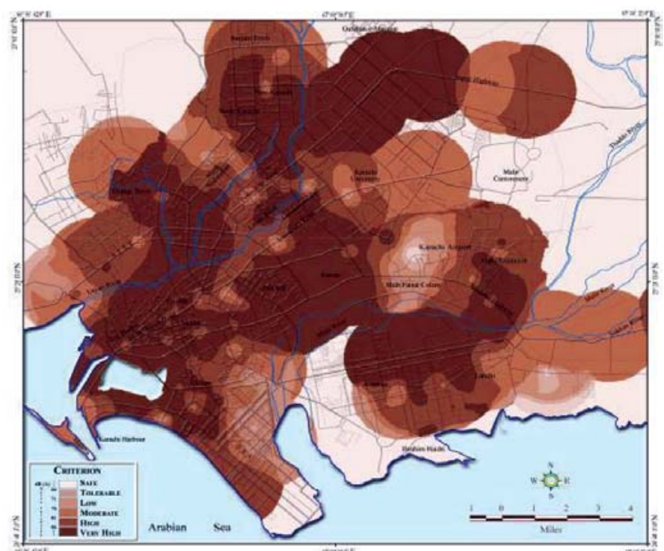


Fig. 8. Weekend mornings: Peak

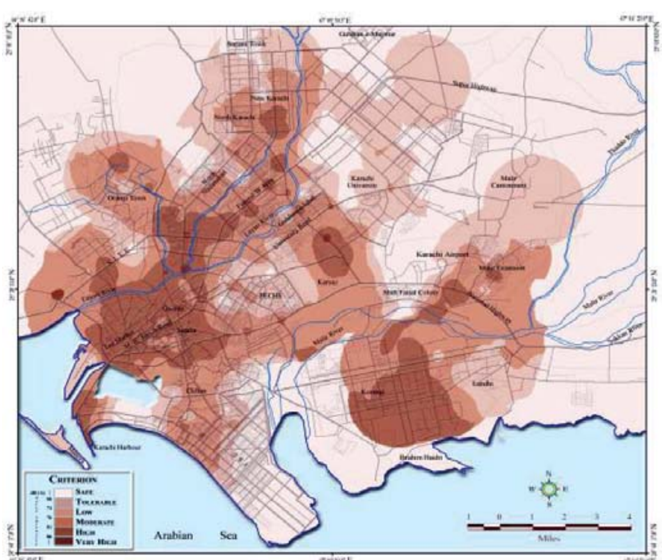


Fig. 9. Weekend mornings: Mode

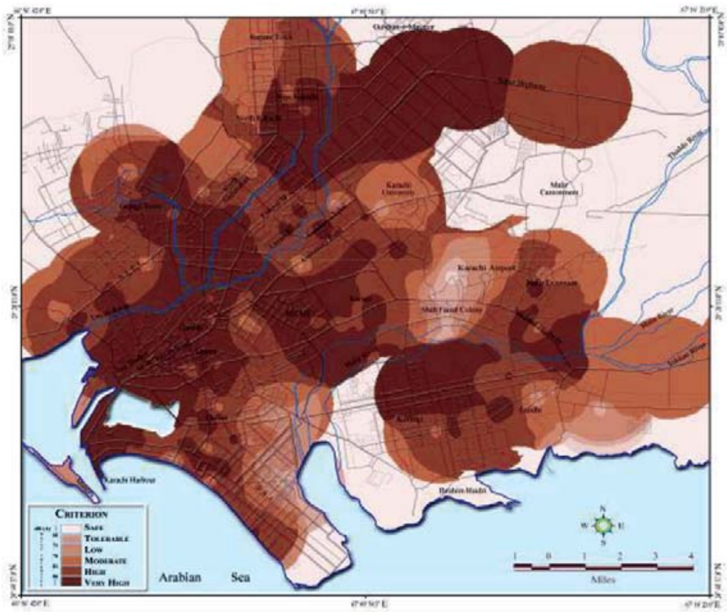


Fig. 10. Weekend afternoons: Peak

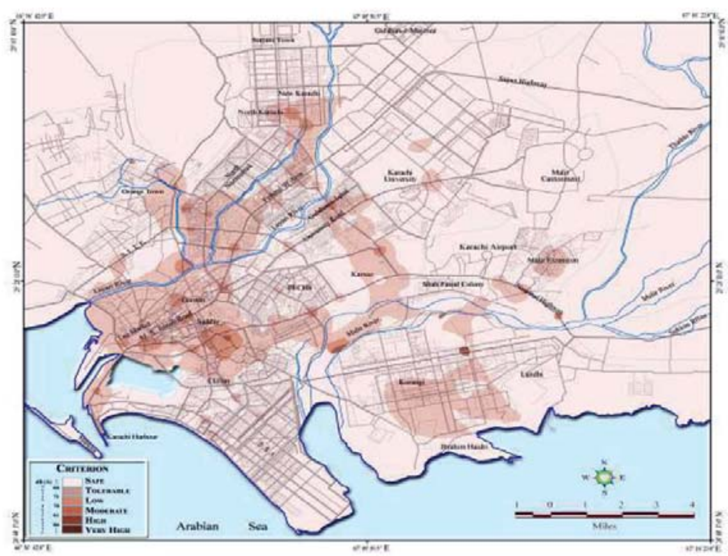


Fig. 11. Weekend afternoons: Mode

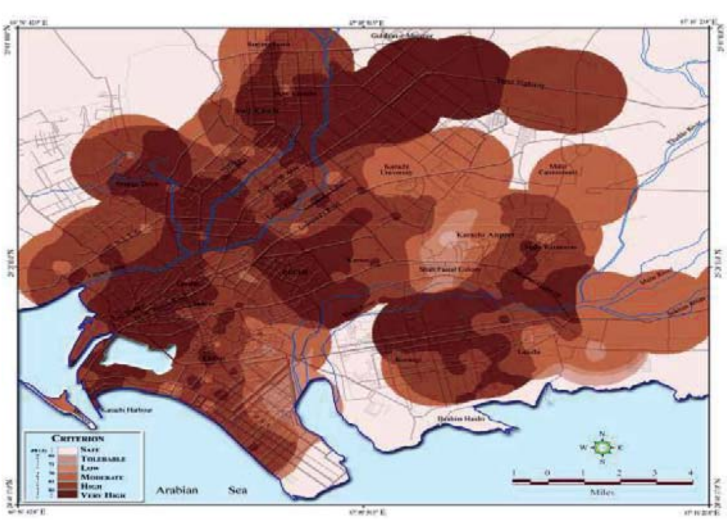


Fig. 12. Weekend evenings: Peak

becomes irrelevant. Here the scenario is influenced by the very-high noise patterns, which cover a large part of the city (see Fig. 8). The boundaries of the maximum noise propagation were inadvertently not taken care of while performing the *surface interpolation*. Huge *noise islands* are clearly manifested in this figure showing very high noise zone all across the city.

The spatial patterns of acoustical variations seem to have direct relationship with vehicular traffic and the concentration of urban activities. The posh and planned neighbourhoods of DHA and societies are under safe and tolerable noise zones respectively. The older parts of the city are under moderate noise. The inadequate roadway width there, has contributed for the sparse clusters of moderate-noise zones around Malir, Grumandir and Empress Market. No spot could be recognized as *noise islands* on this map.

Apart from the cartographic limitations, Fig. 10 shows a slight spatial contraction as compared to the morning situation. The major arterial roads in district Karachi Central are under high to very-high noise. The old city areas in district Karachi-South (former) show spatial similarity. The remaining metropolis falls under moderate noise temporally. Expanded *noise islands* for this particular occasion are vast and clearly manifested in this figure showing very high noise zone all across the city.

Fig. 11 could be discussed considering the propagation behaviour of noise and by comparing it with the spatial patterns of mode readings in the morning. The spatial elongation in tolerable noise clusters can be seen all around the metropolis. Probably, it is the calm period during the whole week. A *noise island* is found at the Empress market (Saddar) due to the bus terminal and retail market.

Only the undeveloped KDA scheme-33 is found safe and the rest of the metropolis portrays a horrific picture (Fig 12). The metropolitan Karachi has enormous social activity during the evenings owing to its cultural characteristics. The congestion at the roads is due to

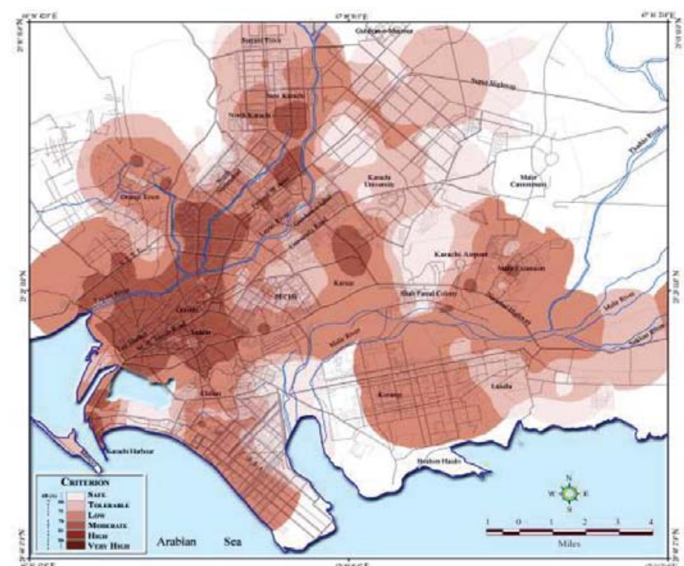


Fig. 13. Weekend evenings: Mode

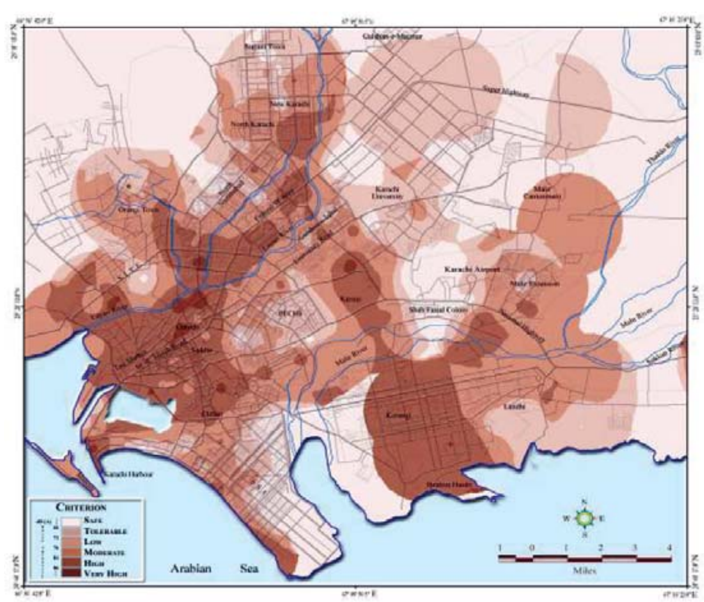


Fig. 14. Weekly average: Mode

different trip purposes. It can be noticed here that the DHA has also fallen under the high noise zone and the entertainment centres of Clifton and sea view are clearly under high noise. Some of the *noise islands* are associated areas of Aladdin and Sindbad amusement parks, Garden area and various 4-legged Intersections of districts Karachi Central and South.

The spatial expansions with respect to afternoon scenario are quite visible but the affected neighbourhoods are more or less similar in Fig. 13. The increase could be explained as the propagation behaviour characteristics of sound. Aladdin Park, Nazimabad Chowrangi, Sea View and Lasbela could be identified as minor *noise islands.*

This output has been generated by means of GIS technique mostly cited under the headings of cartographic algebra or precisely map averaging (*e.g.*[23] ESRI, 1998; [14] Bernhardsen, 2002). The overall state of affairs with respect to noise pollution across the metropolis has been presented in fig 14. There are few neighbourhoods that can be considered as safe (Gulshan-e-Maimar, Malir Cantonment, Ibrahim Haidri and undeveloped phases of DHA). Quite a number of localities are within the tolerable limits of noise (University area, Gulistan-e-Johar, Scheme 33, Surjani Town and North Karachi). Majority of the areas fall under the low noise zone. The most distinct pattern emerged on this map is the moderate noise zone influencing the old city (core) Karachi, and congested areas of Liaquatabad and Nazimabad (populous district Karachi Central). Prominent *noise islands* besides this moderate zone are Malir, vicinity of Nagan Chowrangi and F. B. Area.

Fig. 15 is an illustrative of the overall situation of peak noise levels on the arteries of Karachi metropolis. There are hardly a very few portions of neighbourhoods, which fall under the safe, tolerable and low noise zones. Mostly they are low volume traffic areas. The massive share of the city is under the high peak noise, while about more than 15 % area of the metropolis is constantly under extreme noise

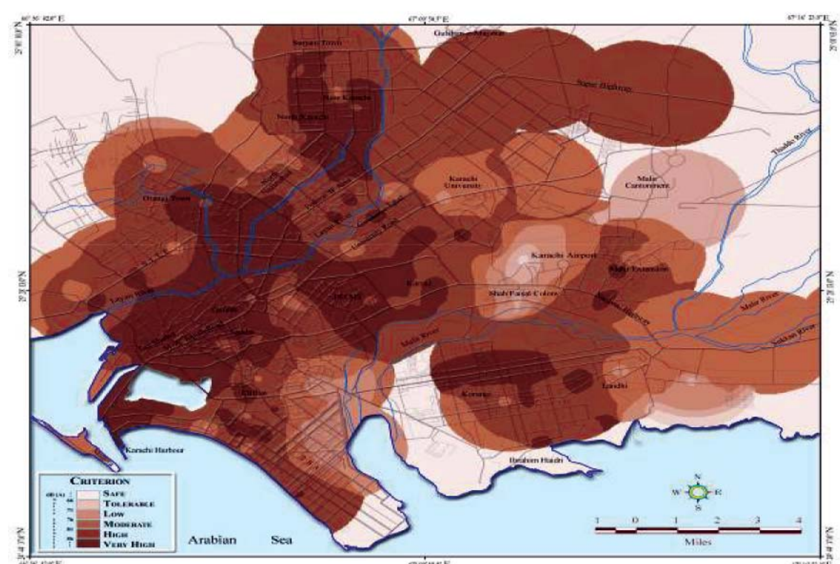


Fig. 15. Weekly average: Peak

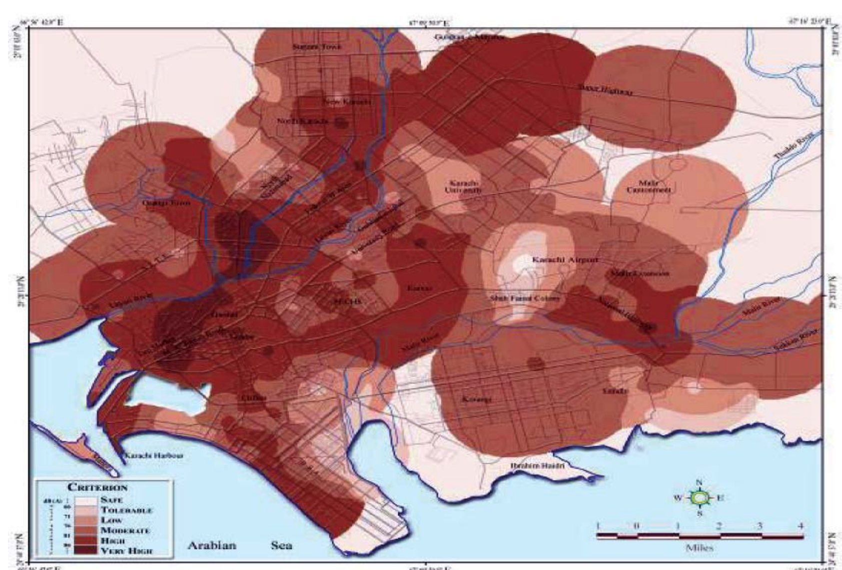


Fig. 16. Weekly average: Mode and Peak

stress. A worthwhile outcome of this map is the formation of a distinct "*very high noise region*" in the vicinity of the most populous neighbourhoods of old city area (core), Liaquatabad, Nazimabad and North Karachi. Besides these neighbourhoods, some isolated intersections and localities which are portrayed in the Fig 15, include Sohrab Goth, NIPA Chowrangi, Johar Morre, Hasan Square, Liaquat Market Malir, Clifton Helipad.

Fig. 16 has been produced through the superimposition of temporal thematic layers of field observation noise intensity levels across the metropolis; at the two specified monitoring dimensions (*i.e.* mode and peak), three predetermined times of the day, and two week wise variations. Here a relationship could be explored between the road density, traffic volume, population concentration and produced noise in the environment. Higher noise levels in this illustration are representing sever threat for the population owing to perpetual noise.

Conclusion

Urban noise and traffic congestion on roads is a major problem, especially since few third world governments have instituted effective noise-control programs on vehicles as in Europe and North America (Hardoy *et al.*, 1992). In some cities like Bangkok, Hong Kong and Jakarta, they are the most visible urban environmental problems (ESCAP, 1990). Findings from Western nations suggest that outdoor noise levels should be kept under 65 dB(A) to comply with desirable limits indoors. While noise pollution remains a major concern in Western nations, at least there are regulations and institutions to enforce them and democratic procedures through which protests can be organized; one or more of these is lacking in virtually all Third World nations (Hardoy *et al.,* 1992). This paper has provided some of the grass root information on noise pollution in an emerging mega city of a *Least Developed Country* (Fellmann *et al.*, 1992).

REFERENCES

1. UNEP, "GEO 2000: Global Environment Outlook", *United Nations Environment Program*, London: Earthscan Publications, 1999.
2. M. R. Mehdi, "Appraisals of Noise Pollution, Traffic and Land Use Patterns in Metropolitan Karachi through GIS and Remote Sensing Techniques" PhD dissertation, University of Karachi, 2002.
3. T. Priede, "In Search of Origins Noise: A Historical Review" *Society of Automotive Engineers International Congress*, MI, USA, 1980.
4. B. J. Challen and M. D. Croker, "A Review of Recent Progress in Diesel Engine Noise Reduction" *Society of Automotive Engineers International Congress*, MI, USA, 1982.
5. SEPA, "The Study of Noise Pollution in Karachi", Government of Sindh Environmental Protection Agency, Pakistan, 1994.
6. S. H. Zaidi, "Noise Levels in Karachi on a Transporters Strike Day", *JPMC, Department of ENT*, Karachi, Pakistan, 1990.
7. "Deafness on Rise due to Noise Pollution", *Dawn*, April 6, Karachi, 1999.
8. ESCAP, "State of the Environment in Asia and The Pacific", *Economic and Social Commission for Asian and the Pacific*, UN, Bangkok, Thailand, 1990.
9. G. H. Sheikh and S. S. H. Rizvi, "Frequency and other Parametric Analysis of Traffic Noise in Karachi City" PCSIR Laboratories, Karachi, Pakistan 1990.
10. M. R. Mehdi, M. H. Arsalan and J.H. Kazmi, "Spotting Noise Risk Zone in Karachi" *Proceedings, Governance and the Use of GIS in Developing Countries, ITC*, the Netherland, May 2002, pp. 23-1 to 23 -6.
11. L. Worrall, *Spatial Analysis and Spatial Policy Using Geographic Information Systems*, London: Belhaven Press, 1991.
12. MIC, *MapInfo Professional: User's Guide Version 5.5* New York: MapInfo Corporation, USA, 1999.
13. T. Bernhardsen, *Geographic Information Systems: An Introduction,* NY: John Wiley, USA , 2002.
14. A. G. Journel and C. J. Huijbregts, *Mining Geostatistics*, London: Academic Press, 1978.
15. I. Clark, *Practical Geostatistics*, London: Applied Science Publishers, 1979.
16. P. Mousset-Jones, ed., *Geostatistics*, London: McGraw Hill, 1980.
17. P. I. Brooker, *A Geostatistical Primer*, Singapore: World Scientific, 1991.
18. C. Geron, A. Guenther and T. Pierce, "An Improved Model for Estimating Emissions of Volatile Organic Compounds from Forests in the Eastern United States" *Journal of Geophysical Research*, 99(D6), 1994, pp. 12773-12791.
19. E. H. Isaaks and R. M. Srivastava, *An Introduction to Applied Geostatistics*, New York: Oxford University Press, 1989.
20. C. V. Deutsch and A. G. Journel, *GSLIB Geostatistical Software Library and User's Guide*, New York: Oxford University Press, 1992.
21. M. H. Arsalan, "Spatial Patterns of Air Pollution: A GIS Perspective" *Proceedings, GIS in New Millennium: 2nd International GIS Conference*, 2000, Pakistan Society of Geographic Information System (PSGIS), Islamabad, 2000.
22. www.soc.titech.ac.jp/~sakano/atiq/conf2000.html
23. M. H. Arsalan, "Monitoring Spatial Patterns of Air Pollution in Karachi Metropolis: A GIS and Remote Sensing Perspective", PhD dissertation, University of Karachi, 2002.
24. ESRI, "Working with ArcView Spatial Analyst", *ESRI Educational Services, Environmental Systems Research Institute* Inc., California, USA, 1998.
25. J. Fellmann, A. Getis and J. Getis, *Human Geography: Landscaps of Human Activities* 3rd ed., USA: Wm. C. Brown Publishers, 1992.
26. J. E. Hardoy, D. Mitlin and D. Satterth, *Environmental Problems in Third World Cities,* USA, 1992.
27. D. G. Harland, "Rolling Noise and Vehicle Noise", *Department of Environment, TRRL Report*, LR652, Transport and Road Research Laboratory, Crowthorne, UK: 1974.
28. J. W. Tyler, *Sources of Vehicle Noise*, UK: Transport and Road Research Laboratory, Crowthorne, 1987.