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Spatial Mapping of Traffic Noise Levels in Urban Areas

by Mohammed Taleb Obaidat

This paper combines field data with an analytical approach to spatially map noise levels due to traffic movements at relatively high traffic volume signalized intersections utilizing the potential of Geographic Information Systems (GIS). Noise data were collected using a discrete mapping technique at 29 signalized intersections, as well as between intersections, and at their respective neighborhood areas in Amman, capital of Jordan. Data were collected in three different highly congested traffic peak periods: 7:30 a.m.-9:00 a.m., 1:30 p.m.-3:00 p.m., and 9:00 p.m.-11:00 p.m. A portable precision sound level meter capable of measuring noise levels from 34 to 134 decibels (dB) was used during the data collection process. The highest recorded noise level at some signals was 80 dB, while the lowest was 34 dB. In fact, some signalized intersections showed higher noise levels than the acceptable or the standard ones, i.e., 65 dB for daytime and 55 dB for nighttime in residential areas at city center. Two-dimensional (2D) vector and raster maps of noise levels, at different time periods for signals' areas and neighborhoods, were spatially displayed. Results showed that the developed GIS maps could be useful for city planning and other environmental management applications for the purpose of: 1) temporal monitoring and queries of noise level changes as a function of time, 2) spatial queries to find the highest noise disturbance location and its time of the day, 3) development of an online noise information system, 4) using noise level based spatial maps as indicators of variation in land prices, and 5) forecasting and current assessment of the acoustic climate of urban areas.

INTRODUCTION

Noise due to traffic movement, hazardous chemical emissions, and radioactivity, i.e., emitting radiation in the form of particles or electromagnetic waves, along with other factors are considered as the major threats to people living in urban areas. Noise disturbance may cause people in urban areas to move or consider moving from cities of high population density in search of a quieter environment. Therefore, local governments and municipalities try their best to create green buffer zones around residential areas of heavy traffic, enforce lower speed limits, or improve recreational areas in order to reduce the dissatisfaction with the environment in residential areas.

Urban areas with high noise disturbance are not attractive as residential zones. Therefore, land prices and the motivation to live near high noise level areas would be decreased. Moreover, the availability of spatial noise level maps would be useful for planners as well as citizens for their decision-making strategies and scenarios. Facilitating the availability of urban noise information would also be useful for the local community and drivers in order to model their traffic behavioral issues.

GIS usage could provide great potential to optimize the quality of noise effect studies because traffic noise and its environmental effect have numerous spatial components. Thus, planners could select urban zoning design with the least environmental impact. Further, integrating noise data with spatial and location data would quantify noise effects in a digital maps domain. These maps could quantify noise levels and their effects based on areas, population density, buildings, and type of buildings. Moreover, selecting a threshold noise level would classify the urban area into acceptable or not acceptable zones for different usage, such as residential, industrial, and commercial. The selected threshold noise level could be chosen based on the noise level standards defined by the

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Environmental Protection Agency (EPA) or the designated comfortable noise level for different zones.

Spatial noise contour maps are useful to urban planning agencies, traffic engineers, cities and governmental agencies, as well as the public to show the distance from a roadway to other land uses in order to keep the noise level below the noise level abatement criteria for all land use types. Further, they can be used as indicators to identify factors that influence traffic noise levels near roadways, manage the land use planning process, quantify the noise effect on the surrounding neighborhood and developed infrastructure, develop an online traffic noise information system, perform spatial queries to find highest noise disturbance location at any time of the day, and control variation in land prices.

This paper will present the potential of using GIS, along with field data and an analytical approach to spatially map noise levels at different times of the day, in order to assist decision-making and planning tasks at the municipalities' level. It is anticipated that this study will promote the use of standardized methods to quantify noise effects and to allow noise studies to be conducted in an automated manner.

LITERATURE REVIEW

It is well known that road traffic noise could be due to traffic volume, traffic composition, speed, noise screens, distance from the source of noise, reflection of noise from barriers, retaining walls or mitigation techniques, weather condition, terrain, road surface, and grade. Many studies have focused on these factors and their effects on noise levels, however, studies incorporating and integrating noise level factors within new technologies, such as GIS and computer vision, have been few (Thanaphan and Monthip 1999).

The U.S. EPA (2005) has established 70 dB as a safe average for a 24-hour day. Since sound intensity doubles with every increase of three dB, the time of safe exposure would be cut in half with each such increase. Thus, a worker should wear ear protection if exposed to a steady 75 dB for eight hours, 78 dB for four hours, and so on. Brief exposure to noises up to 100 dB is not considered risky provided the average remains within the prescribed levels (EPA 2005).

The U.S. Federal Highway Administration (FHWA) has created and maintains a comprehensive Traffic Noise Model (TNM) program that predicts noise contours around roadways, taking into account roadway geometry, traffic patterns and vehicle distributions, noise barriers, buildings, surfaces over which the noise must travel, elevations of the receivers, type of pavement, and numerous other variables that can be used to very accurately predict urban noise from GIS-type information and traffic data (Hankard et al. 2006; Colorado Department of Transportation 2006). However, these noise models may not be applicable in a developing country like Jordan due to the existence of different factors and conditions that might include roadway traffic percentages and types, road geometry, terrain type, environment, existence of noise barriers, and other numerous factors.

In Jordan, Alhiary (2002) developed statistical models to predict and evaluate equivalent, maximum and minimum noise levels for signalized intersections at Amman, Jordan. Noise levels were predicted as function of traffic volume, vehicle speed, distance to intersection, road geometrical parameters, heavy vehicles percentage, and pavement surface texture. The study recommended performing traffic noise measurements at different lateral distances from the intersections to produce contour maps for noise levels, i.e., maps containing lines connecting points having the same noise levels.

The integration of GIS and noise data models potentially could increase the generation of noise data-models from spatial data in an automated manner. This could give the decision makers and planners an insight to quantify the noise effect on the surrounding neighborhood and developed infrastructure. Moreover, GIS usage in noise studies has numerous advantages such as the following (Stoter 1999):

1. Increasing the quality of the study on noise pollution
2. Supporting environment management
3. Decreasing the cost of noise studies
4. Forming a link between geographical and geometrical information of the surrounding environment and the noise prediction model
5. Calculating the impact of noise on the environment
6. Providing a monitoring and quantifying noise tool
7. Presenting, storing, managing, manipulating, analyzing, and visualizing capabilities of the database

Muller et al. (1999) and Servigne et al. (1999) developed a solution for urban noise representation using discrete and continuous mapping using conventional and multimedia settings. They produced an interactive acoustic noise map. However, they didn't consider psychological and temporal dimensions. Therefore, the usual GIS spatial queries were used; temporal queries were not used due to unavailability of noise data within a particular time period such as a day, week, or month. They concluded that further research work is needed to extract detailed information about the requirements of experts that will work with an urban noise information system in a continuous daily planning process.

Yamaguchi and Kato (1998) studied noise at intersections in urban areas. They developed models to predict noise time histories, histograms, and indices at various locations around the intersection and indicated that the actual road traffic noise is affected by traffic signals. Thus, the random noise fluctuations exhibit periodic non-stationary properties caused by the periodic temporal change of traffic flow.

The integration of GIS with noise level data potentially could overlay noise emission contours upon spatially geo-referenced information. However, we still need digital noise maps that could do the following activities: cover the area surrounding buildings or a selected road, identify numbers of people exposed to different levels of traffic noise, predict indoor noise levels, validate a predicted noise level with a measured one, answer "what if" questions, determine the effect of traffic management measures, identify the effect of constructing a new building or noise barrier on the environment, and provide advice on noise management techniques. A noise-mapping method could be used to calculate the number of residences exposed to noise, noise propagation in the terrain, and noise levels in specific locations.

In this paper, spatial maps will be used to draw two dimensional (2D) GIS noise levels maps at different time periods for signalized intersection areas and their associated neighborhoods.

DATA COLLECTION

Noise levels due to traffic movement and traffic volume variations were measured at different signalized intersections and their corresponding surrounding regions. Noise data were studied at 27 signals of four zones in Amman, Jordan, that recently received about one million compulsory immigrants of neighboring countries. As far as noise pollution is concerned, these immigrants, without any doubt, contributed negatively to the environment. These zones included the largest as well as the highest land prices of residential zones in Amman: Tla' Al-Ali, Wadi El-Seer, Al-Abdali, and Zahran. Except Al-Abdali zone, which is a mix of residential and commercial areas, the zones mainly represented residential areas. Table 1 shows the characteristics of the studied zones and their respective signals. The studied zones were about 125 km² in area and 360,000 in population. They have 27 traffic signals of average traffic volumes ranging from 25 to 60 vehicles/minute. The percentages of vehicles' classifications or types were about 84% for passenger vehicles, 6% for trucks, and 10% for minibuses, buses, and public transportation vehicles. Traffic signals were located at intersections having three and four legs, i.e., roads radiating from the intersection and forming part of it, having different traffic volumes and geometric parameters including roadway

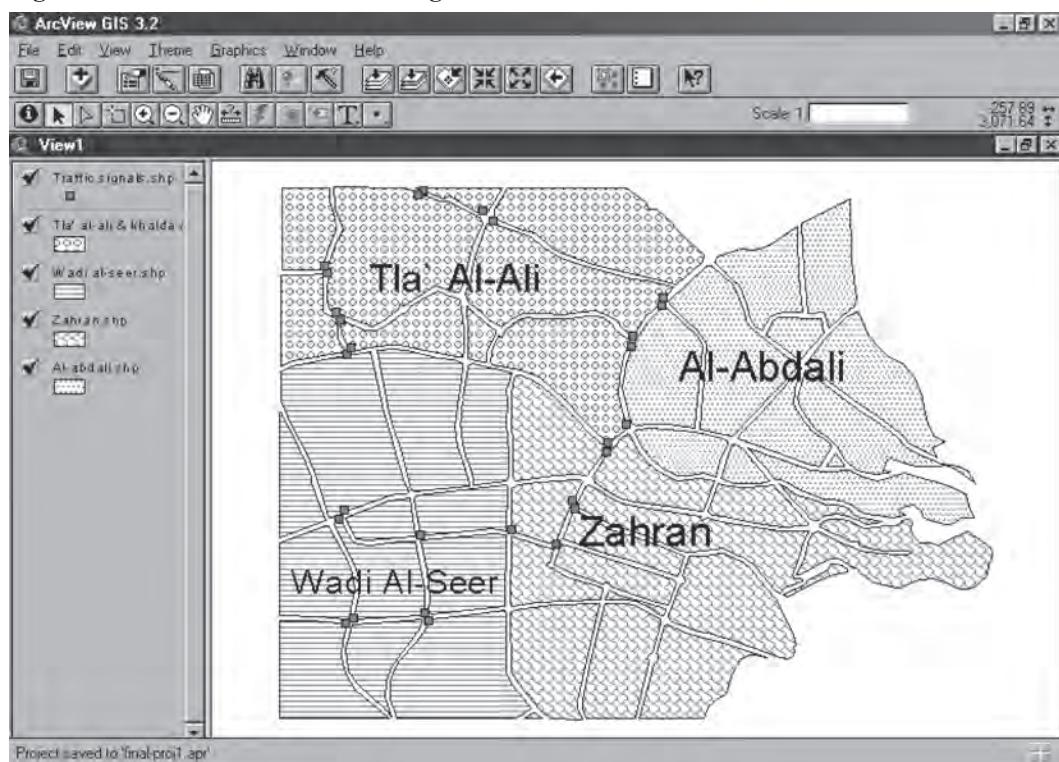
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slope, number of lanes, and lane width. Figure 1 shows the studied zones and the traffic signal locations.

Table 1: Characteristics of Studied Signals and Zones

Zone Name	Number of Traffic Signals	Area (km ²)	Average Speed Km/hr	Average Number Vehicle/Minute	Population	Zone Type
Al-Abdali	4	15	50	40	120,000	Mix of Residential and Commercial
Wadi El-Seer	7	39	60	25	85,000	Residential
Tia' Al-Ali	10	25.2	50	60	85,000	Residential
Zahran	6	45	40	25	70,000	Residential

Figure 1: Studied Area and Traffic Signal Locations



The data collection procedure used the Precision Sound Level Meter Type 2232, which was capable of measuring noise levels within the range of 34 to 130 dB. Noise data were collected at the following three locations:

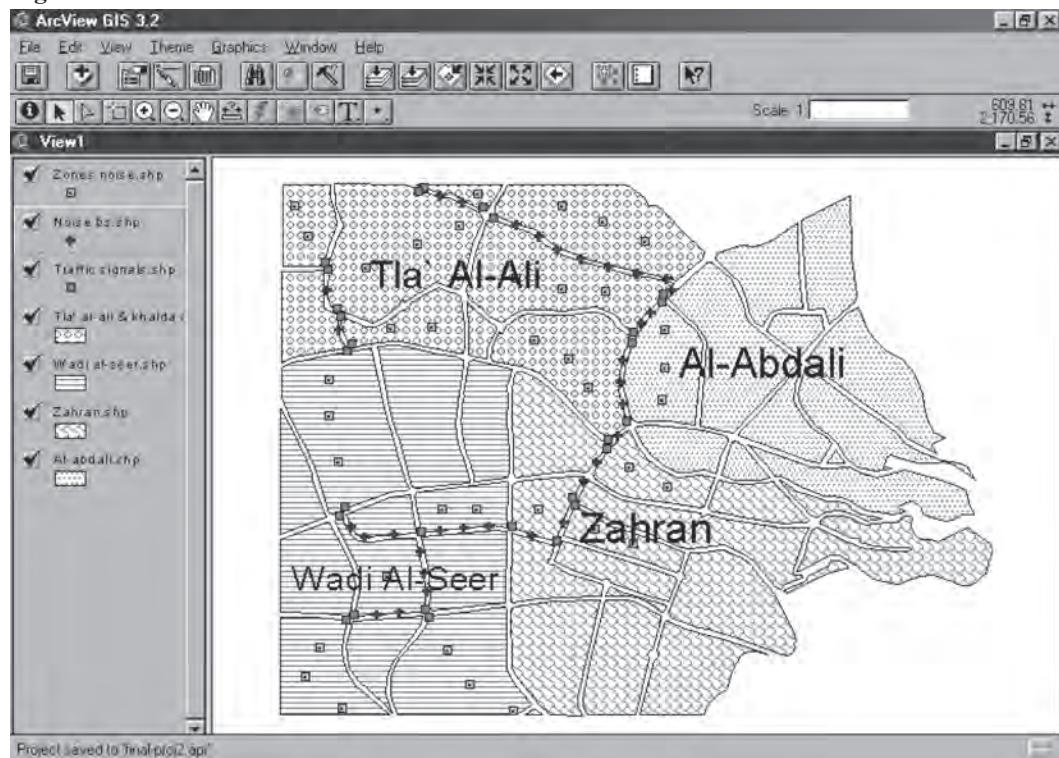
1. At traffic signals approaching legs
2. At the road between traffic signals
3. At the surrounding neighborhood

It is worthwhile mentioning here that the instantaneous Sound Pressure Level (SPL) was used on the noise meter instead of the A-weighted equivalent noise levels (L_{eq}) function because of its availability at the highway laboratory of Jordan University of Science and Technology (JUST).

The equivalent noise level is defined as the steady A-weighted level that is equivalent to the same amount of energy as that contained in the actual time-varying noise levels over a period of time—typically over one hour. The A-weighting scale is an adjustment to the actual sound power levels consistent with that of human hearing response, which is most sensitive to frequencies around 4000 Hz and less sensitive to low frequencies below 100 Hz. The L_{eq} function has the potential to give an integrated noise measurement over a period of time that is better correlated with the perception of the receivers at roadside.

The procedure used in this study is the *ISO 11819-1 Acoustics – Measurement of the Influence of Road Surfaces on Traffic Noise – Part 1: Statistical Pass-by Method* (1997). It provides a comprehensive standard for the method of roadway noise measurement, the distances to place the meters, and the sampling methodology to assess the effect of vehicle mix and traffic peak (Hankard et al. 2006; Colorado Department of Transportation 2006). This procedure is commonly used in Jordan (Alhiary 2002). Traffic noise levels of the signalized intersections were measured near the traffic signal, i.e., about three to five meters from the traffic signal. However, noise levels between signals were measured at regular distance intervals of about 100 m and measured at diagonal or circular lines for the surrounding or adjacent neighborhood every 50 m. The noise level measurements were recorded during summer, and the study areas had no noise retaining wall barriers at the side of the roads. Figure 2 shows the locations where noise levels were measured.

Figure 2: Locations of Noise Data Collection



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Data collection time was divided into the following three periods:

1. The morning period from 7:30 a.m. to 9:00 a.m.
2. The afternoon period from 1:30 p.m. to 3:00 p.m.
3. The evening period from 9:00 p.m. to 11:00 p.m.

It has to be noted here that the measured noise level at every point was repeated three times, and the average values were used in this study.

GIS LAYERS

Different GIS layers (themes) were developed in order to identify entities, attributes, and relationships of the measured noise levels with different studied variables. These layers included the following:

1. Zones of the studied area. The following attributes were used for this layer:
 - *Shape*: The type of shape of the specific zone (Polygon)
 - *Zone_Name*: The name of the zone
 - *Zone_Id*: The unique identification number of the zone
 - *Zone_Area*: The area of the zone in km².
 - *Zone_Population*: The population of the zone
 - *Zone_Class*: Zone classification; residential or commercial
2. Signals within the zones of the studied area. The following attributes were used for this layer:
 - *Shape*: The type of shape of the signal (Point)
 - *Signal_Approaches*: Number of legs of the intersection having the specific signal
 - *Volume*: Average number of vehicles/minute for the legs of the intersection
 - *Signal_Time*: Signal timing
3. Roads within the zones of the studied area. The following attributes were used for this layer:
 - *Shape*: The type of shape of the road (Line)
 - *Road_Name*: The name of the road
4. Measured noise levels for the morning, the afternoon, and the evening periods, including measurements at the signals, at the roads between signals, and at the surrounding region. The following attributes were used for this layer:
 - *Shape*: The type of shape of the location (Point)
 - *Noise_Level_Morning*: The measured noise level for the morning period
 - *Noise_Level_Afternoon*: The measured noise level for the afternoon period
 - *Noise_Level_Evening*: The measured noise level for the evening period

Table 2 shows the statistical characteristics of the collected noise level database.

Table 2: Statistical Characteristics of Measured Noise Levels Data

a. At Traffic Signals

Characteristics	Range (dB)			Average (dB)	Standard Deviation (dB)
Study Period	Number of Measurements	Minimum	Maximum		
Morning Time	27	46	79	58.6	6.4
Afternoon Time	27	45	78	59.2	7.2
Evening Time	27	39	74	55.6	7.0

b. Between Traffic Signals

Characteristics	Range (dB)			Average (dB)	Standard Deviation (dB)
Study Period	Number of Measurements	Minimum	Maximum		
Morning Time	33	39	80	49.3	7.2
Afternoon Time	33	37	77	50.1	6.8
Evening Time	33	34	72	45.3	7.1

c. At the Regions Surrounding the Signals

Characteristics	Range (dB)			Average (dB)	Standard Deviation (dB)
Study Period	Number of Measurements	Minimum	Maximum		
Morning Time	24	34	42	37.8	2.6
Afternoon Time	24	34	40	38.3	2.4
Evening Time	24	34	39	36.9	2.2

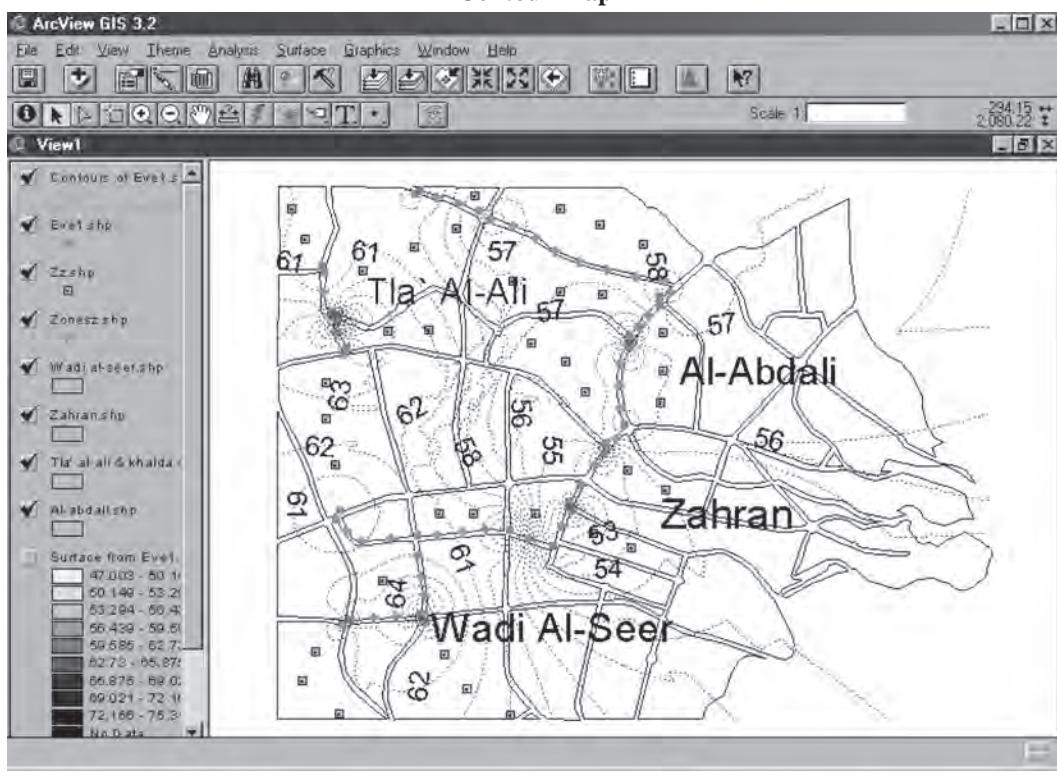
NOISE LEVEL MODELS

Spatial distribution and contour maps of noise data were mapped for the three studied periods using Arcmap GIS software. Figures 3, 4, and 5 respectively show contour and spatial maps for the morning, afternoon, and evening periods. Contour maps are at the top of the figures, while, spatial maps are at the bottom. For each spatial map, a numeric noise level value was assigned for each grid of equally sized cells. Continuous surfaces that lack definite boundaries were generated for noise levels. These surfaces have the advantage of finding the noise level at any point within the scene regardless of whether the point is at the intersection, between signals, or at the surrounding neighborhood. Moreover, a spatial overlay process was used to produce a wide range of mathematical operations on noise level cells.

Figures 3 through 5 represent contour (vector) and spatial GIS maps for the morning, afternoon, and evening measured noise levels generated from the measured noise levels of the roadway traffic. They show the temporal and spatial noise level variations due to traffic for every pixel or location. It is obvious from the maps that noise levels increase near traffic signals and roadways. However, noise levels decrease while going far away from the roadway. These maps could be useful for interpreting traffic noise at any time of the day for any location. Thus, they could be used as indicators for citizens and city planners to know the boundaries of annoying noise levels at residential areas or any other land use. Therefore, city planners could generate classified noise level maps that show acceptable or non-acceptable noise level boundaries for any land use zones, such as residential, industrial, schools, and hospitals. These noise level maps could also be used as indicators for

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Figure 3: Contour and Spatial Maps for Morning Period
Contour Map



Spatial Map

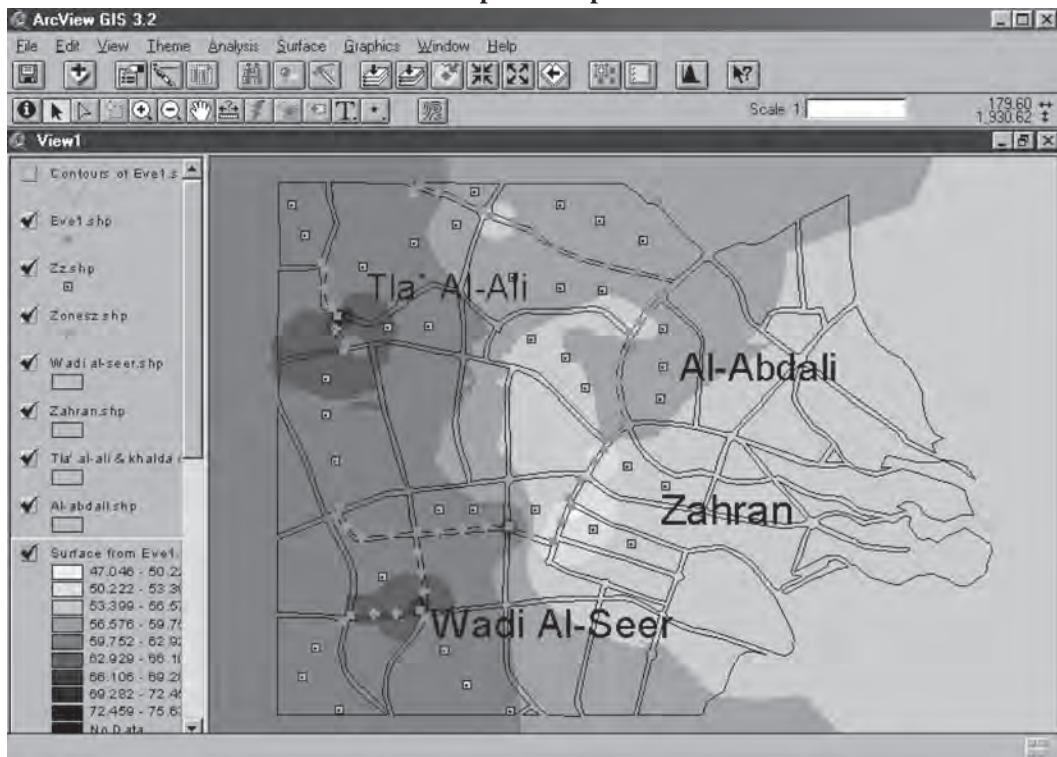
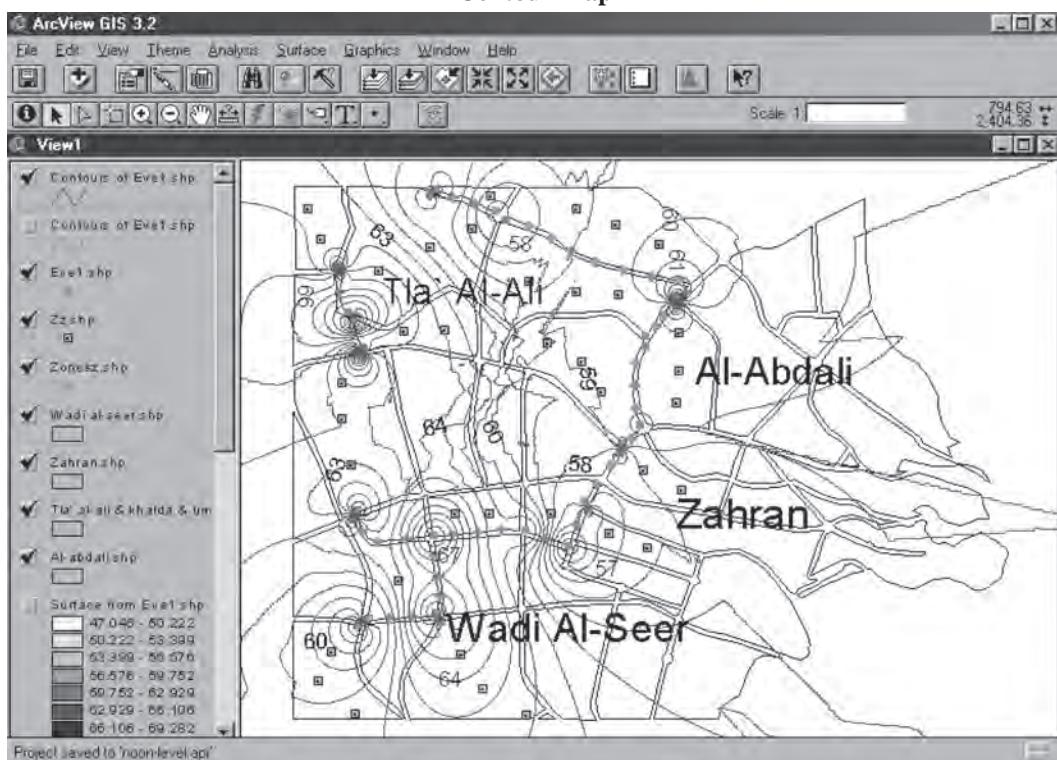
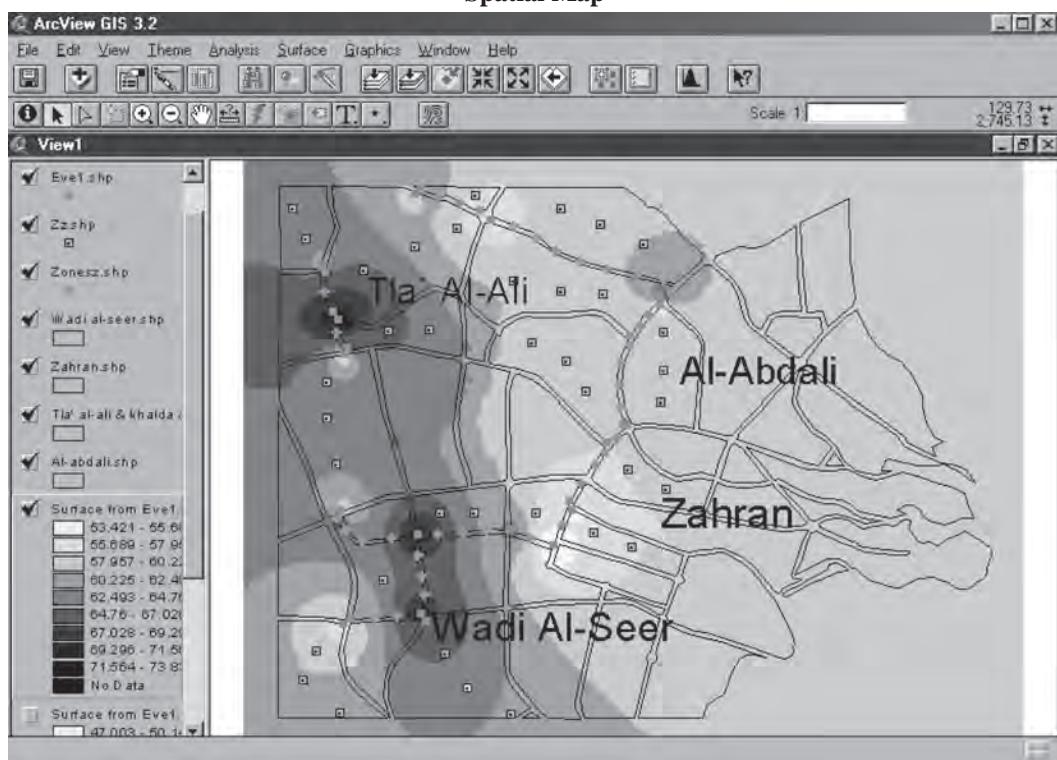


Figure 4: Contour and Spatial Maps for Afternoon Period

Contour Map



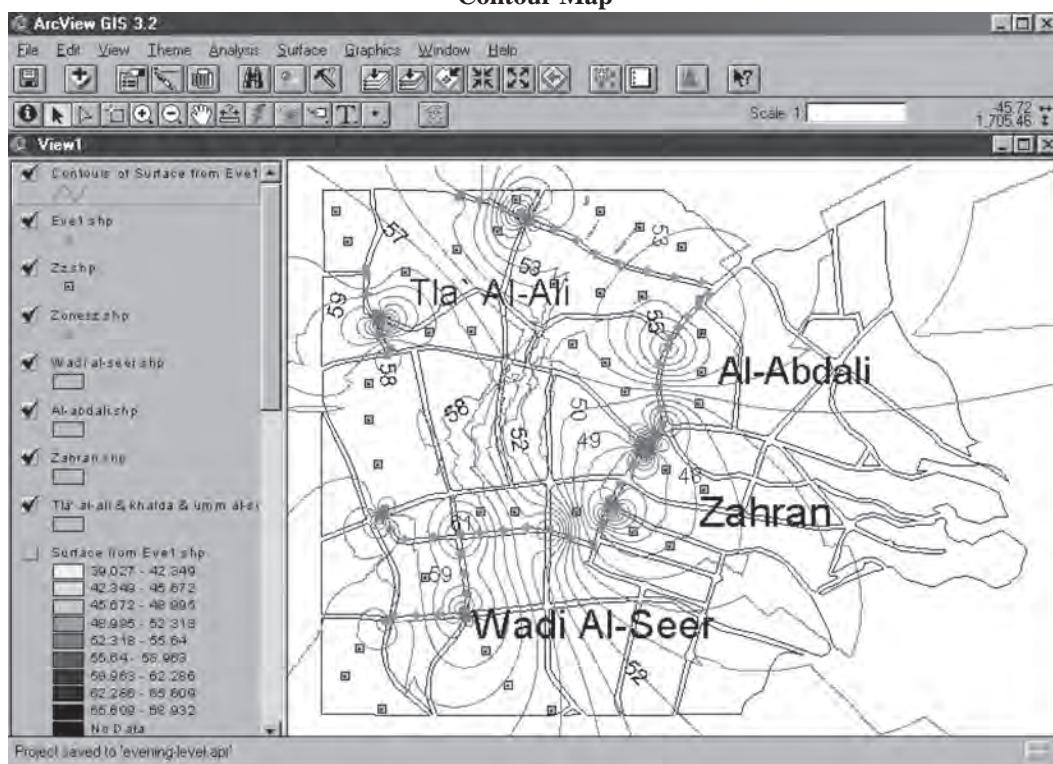
Spatial Map



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Figure 5: Contour and Spatial Maps for Evening Period

Contour Map



Spatial Map



variations in land prices, spatial queries to find the highest noise disturbance location at any time of the day, and development of an online noise level information system.

In Figures 3 to 5, spatial modeling techniques could also be used to simulate the spread of noise levels data due to traffic movement and to locate the suitable boundaries for the zone area according to international standards. The international noise standards represent the legislations in developed countries, such as the United States, United Kingdom, or Canada. However, in Jordan these standards are limited to that listed in Jordanian Environmental Protection Law, i.e., 65 dB and 55 dB for residential areas at city center during daytime and nighttime, respectively. Using the acceptable threshold noise level data, city planners could locate and classify the suitable zones for residential, commercial, or industrial land use. For example, using 54 dB as an acceptable noise level threshold value for residential areas in Jordan, Figure 6 shows a spatial map for the evening period that predicts the boundaries of the acceptable zones where citizens can build their houses without noticeable noise levels. In Figure 6, the black areas with high noise levels are not suitable for residential areas; however, the white areas with fewer noise levels are the most suitable.

Further, with the spatial model of noise level for any period of time, surface maps, sophisticated models, distances, slopes, aspects, statistical tables, grids, charts, and decision support tools could be built to simulate real-world processes of noise levels due to traffic movement.

DISCUSSION AND ANALYSIS

The variables involved in the generation of traffic noise may include traffic volume, road geometry, traffic speed, heavy vehicles traffic, road surface texture, and distance from the traffic signal. However, the main factor affecting equivalent noise levels is traffic volume. Figures 3 through 5 show higher noise levels for all periods studied for Tla' Al-Ali and Al-Abdali zones. These two zones had high traffic volumes, averaging 60 and 40 vehicles/minute, respectively. It was quite clear that at regions known for high traffic volumes, as traffic volume increases, higher equivalent noise levels were monitored, such as the Al-Madeena Al-Tebiyah and Dayr Ghbar-Airport signals. (Black heart and triangle appear on the upper part of Figure 3.) Moreover, as distance from the traffic signal increases, the effect of increased traffic volume on noise becomes less important. This was because of the increase in the effect of other variables, such as traffic speed, on the equivalent noise levels as distance from the signal stop line increases. Tables 1 and 2, as well as Figures 3 through 5, show the trend and spatial variation of noise level and its correlation with traffic volume for the three studied locations: at traffic signals, between traffic signals, and at the surrounding neighborhood. The trend is obvious from Figure 5 for the Tla' Al-Ali and Wadi Al-Seer zones with dark color.

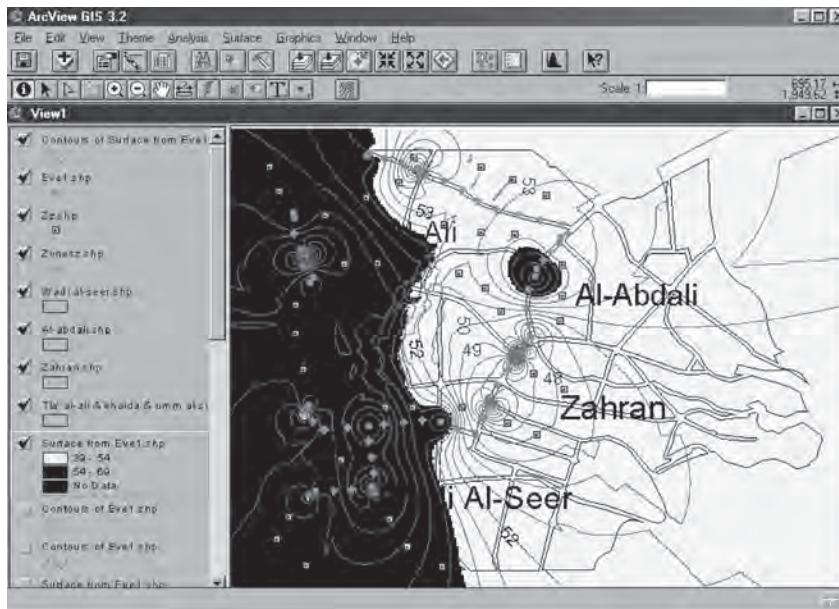
At far distances from the signal stop line, the effect of traffic speed on Leq was higher than the effect of traffic volume. Table 1 shows the average running speed and the traffic volume in terms of number of vehicles/minute. For example, Table 1 and Figures 3 through 5 show that the noise level at Wadi El-Seer zone was higher than Al-Abdali zone, even though the traffic volume at Al-Abdali was higher. This was because the average running speed at Wadi El-Seer was 60 km/hr as opposed to 50 km/hr for Al-Abdali. Also, as the gradient of the approach increases, the noise levels increase. This is because vehicles exhibit higher engine horsepower as the upward gradient of the road increases. In fact, the maximum noise levels were found to be highly affected by the existence of heavy vehicles on the intersection. As the number of heavy vehicles increases, the maximum noise levels increase. When the vehicles used horns, the noise level also increased. Equivalent noise levels were affected significantly by distance from the intersection. Noise levels at distances from the signal stop line were less than those at the signal stop line due to less generated engine horsepower as distances from the signal stop line increased. (Figures 3 through 5 show dark color noise levels with higher values at signals.)

When comparing the values of the maximum measured noise levels with the maximum allowable standard noise levels, it was found that the maximum measured noise level was 80 dB, which didn't exceed the values recommended by Canada, Singapore, the United States, or United Kingdom. The

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international standards for these countries in dBs are 85-90, 85, 90, and 85-90, respectively (EPA 2005). However, the Jordanian standards for noise levels in dBs for days and nights, respectively, are 60 and 50 for residential areas in cities, 55 and 45 for urban areas, 50 and 40 for residential areas

Figure 6: Classification of Zones into Suitable or Not-Suitable Residential Areas



in villages, 65 and 55 for residential areas at city center, 75 and 65 for industrial areas, and 35 and 45 for educational institutes and hospitals (Alhiary 2002). This is an indication of acceptable noise levels that are compatible with international and local standards.

Tables 1 and 2 as well as Figures 3 through 5 show the temporal variations of noise levels with time. During the daytime period, the noise level registered the maximum values due to the existence of heavy traffic volumes. However, the evening period had the minimum values of noise due to the reduction of traffic volumes. Moreover, noise levels could be found at any location for every pixel of the generated spatial maps. Thus, the potential of spatial analysis gives both time and location noise levels analysis capabilities. Noise levels for any period of time decreased as the distance from the traffic signal increased. A similar trend appeared for areas between signals and the surrounding neighborhood.

The same concept of spatial mapping used in generating Figure 6 could be easily adopted in order to produce spatial contour maps of land prices, comfort levels (artificial background noise that does not annoy human beings), land use, noise pollution levels, commercial activities, and environmental or climatic factor levels based on measured noise levels. These maps are vital for city planners and traffic engineers as well because they can show the minimum distance between a roadway and any development from the perspective of noise level, help manage the land use planning process, perform traffic impact studies, and measure variation in land prices.

The noise levels obtained from this study for the measurements done near traffic signals were compared with the noise model of the TNM with the same conditions of 6% trucks and 50 to 60 km/hr running speed. It was found that the average predicted noise level from the TNM was 61 dBA, while the average measured value by the model used in this study was about 58.5 dBA (Hankard et al. 2006; Colorado Department of Transportation 2006). This is an indicator of the compatibility of the two noise models and their high correlation factor.

A scheme could also be adopted to assess the noise pollution level at any location of the spatial map using the tasks performed in this research work. The scheme starts with the selection of

intersections to be evaluated. Then, noise data could be collected using any traffic noise measuring instrument. Next, any GIS software could be used for spatial mapping. Finally, measured noise levels could be compared with the standard ones to identify factors affecting traffic noise.

CONCLUSIONS AND RECOMMENDATIONS

The potential of spatial mapping when combined with field data and an analytical approach for studying traffic noise levels was investigated. A scheme was developed specifically to produce temporal as well as spatial GIS maps for traffic signal areas and their surrounding neighborhoods. Spatial modeling was used to simulate the spreading of noise levels generated by traffic movements and to locate the suitable noise level boundaries for the zone areas according to local and international standards. Spatial maps are vital for city planning and traffic engineers for the purpose of zoning and land use, land pricing, and traffic management.

The following conclusions are the most significant findings of this research work:

1. Spatial GIS shows a great potential in mapping traffic noise levels in the domains of temporal mapping, spatial mapping, and selection of suitable areas for residential or other land uses.
2. Spatial contour maps generated from noise levels of traffic movements could be used as indicators for land prices, human beings' comfort levels, commercial activities, and environmental or climatic factor (temperature, rainfall, relative humidity, and weather-related stand disturbance) levels based on measured noise level are also possible.
3. Spatial maps clearly showed that noise levels reach maximum values at or near the traffic signals and decrease gradually with increasing distance from signals.
4. Despite the high noise levels measured at heavy traffic volumes in Amman-Jordan, these levels are within international standards.

Although the feasibility of utilizing spatial GIS in studying temporal and spatial traffic noise levels had been demonstrated successfully, the following points may deserve further investigations:

1. Expand the use of spatial GIS to set standard traffic noise regulations, strategic planning of land use based on traffic noise level, and assessment of traffic noise influence on road management systems.
2. Investigate the development of an online and real-time traffic noise-based information system.
3. Provide forecasting spatial noise models based on traffic growth.
4. Expand the methodology presented herein to study other factors, such as noise in rural areas, noise of different vehicle types, and noise for different geometrical and environmental conditions.

Acknowledgement

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