Evaluating noise and pollution indices for the Al-Kufa road network

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Abstract. Determining effective countermeasures and solutions to environmental problems caused by traffic congestion, is a vital task especially in urban areas. This study's primary purpose was thus to evaluate the road network in Al-Kufa city using several indices, such as noise and pollution. Limited previous studies have discussed the assessment of Al-Kufa road network, creating a need to determine the best means of evaluating noise and pollution levels among the standard options. Noise and pollution were thus investigated for different roads in the city based on field data at peak periods of traffic flow. The results were used to assess the levels of noise and pollution on the tested roads in the network, with the analysis indicating that both noise and pollution levels are generally higher than standard values. Some short- and long-term suggestions to develop more suitable sustainable operational characteristics were thus offered.

Keywords: Air pollution; Kufa city; Noise pollution; TransCAD.

1. Introduction

Across most developing countries in the last two decades, the demand on road networks in urban areas has gradually increased, increasing traffic congestion and causing increases in the most dominant air pollutant emissions such as carbon dioxide (CO₂), lead (Pb), and noise. Highway sound waves in particular are always considered unwanted noise [1].

Most predictions suggest that the number of vehicles over the next three decades will double, which would cause significant congestion leading to more pollution in urban areas [2]. In addition, as the duration of congestion increases, fuel consumption levels will also increase, resulting in high levels of vehicular emissions such as carbon monoxide (CO), carbon dioxide (CO₂), hydrocarbons (HCs), and nitrogen oxides (NOx) [1], increasing concern about the environment. Motor vehicle emissions represent 90% of air pollution, and the adverse effects of these emissions hurt not only people but also animals and plants. The pollution resulting from vehicles is also difficult to control due to vehicle mobility [3]. Motor vehicles produce various harmful air emissions, some of which have impacts that are localized, while others are harmful globally or regionally; location is thus of little significance. Emission-control systems have helped reduce emission levels of certain contaminants, yet issues remain with multiple contaminants, including particulates[7].

Carbon monoxide (CO) is a deadly poison gas that results from the incomplete combustion of fuel. CO is widely known as the "silent killer", and its toxicity derives from its ability to bind to haemoglobin more strongly than oxygen does, leading to an increased risk of asphyxia-related deaths at high-exposure levels or hypoxic damage to tissues at lower concentrations [19]. Controlling and
reducing traffic pollution has thus become one of the main focuses of sustainable traffic development [4], as equipment operated by internal combustion engines, such as cars produce high levels of CO, and the concentration of this gas is measured in parts per million (ppm) [4].

Gas emissions depend on the speed, acceleration, and vehicle performance levels of passenger car units and trucks. Based on the figures for these states, idling produces ≤50% of total emissions, accelerating gives 35 to 40% of total emissions, and decelerating causes ≤10% of total emissions [5]. Large vehicles such as buses and trucks produce CO emissions (diesel fuel) equal to about 1/11 of those for the equivalent number of small cars (benzene fuel), however [6].

Several issues affect emission ratios:
- Old buses have less effective systems of emission control.
- Faster acceleration increases the rates of emission.
- Rates of pollution are comparatively higher in old engines.
- Per mile emissions increase under stop-and-go conditions and at high and low speeds [8].

Vehicle emission models are thus affected by three main aspects: vehicle design and condition, traffic volume and composition (proportion of heavy vehicles), and road specifications [9]. Environmental considerations have thus recently become an essential part of the planning process alongside engineering and economics[10].

The term noise refers to any unwanted or undesired sound. Noise can also be defined as when the sound level goes beyond an agreed standard level and creates annoyance e[11]. Noise pollution is always annoying, but in recent times it has become recognised as one of the major factors impacting the quality of life in urban areas across the world [12]. Traffic noise levels mainly depend on
- Engine noise, inlet, and exhaust noise, street surface noise, and cooling fan system transmission noise.
- Traffic volume, travel speed, traffic compression, and traffic compression at junctions, as noise increases due to changes in speed.
- Spatial dimension of the roadways and the surrounding building heights [13].

According to [14], the primary sources of noise are
- The surface of the road, at around 55%, due to a lack of maintenance of the surface layer of the pavement within the network.
- Intersections at about 64%.
- Extreme high noise levels due to vehicle alarms at about 55%.

The suggested air quality specification for both noise and emissions offered by the EPA (2009) for Iraq is as follows [14]:
- Noise: 55 dB.
- Lead: 2 microgram/m³.
- SO₂: 40 ppb.
- CO: 35 ppm
- NOx: 5 ppb.
- CO₂: 300 ppm.

2. **TransCAD 4.5**

TransCAD is the only software package that fully integrates GIS with demand modelling and logistics functionality, which it ideal for multiple transportation applications, including
- Network Analysis
- Transportation Planning and Travel Demand Modelling
- Transit Analysis
- Traffic Assignment
- Vehicle Routing and Logistics.
3. Study area

The study area was Al-Kufa city, located in the north east of Al-Najaf, as shown in Figure 1. As an important historical and religious centre, the city has become a popular gathering place for many visitors, which has increased its local importance and contributed directly to the city’s development and urban growth. Most of the roads, however, suffer from severe traffic jams during rush hours, which increases delays for users. This congestion results from a lack of capacity in the streets and intersections due to recent substantial increases in the use of private transport modes, which are now seen as a more reliable source of transportation due to the deficiencies of public transportation [17].

![Figure 1. Location of Al-Kufa city[16].](image)

4. Methodology

This study aimed to calculate the carbon monoxide (CO) emissions and noise levels in Al-Kufa city. The main method of evaluating the noise and pollution levels was the collection of data in the field, including traffic volumes for the relevant streets, calculated using a manual count system.

5. Collected and calculated data

Fieldwork was implemented for various traffic flow characteristics (volume, speed, density, and traffic types). Additional data required to develop the regression equations were collected, such as the heights of the buildings bordering the street, road widths, and the rate of local forestation, as a dummy variable, as indicated in Table 1. This study measured sound levels in all links of Al-Kufa city using a Digital Sound Level Meter (Victor 824A), which measures sound levels in decibels, as shown in Figure 2. The work also examined the noise sources and their causes using a questionnaire survey. A roadside survey questionnaire was conducted based on sampling drivers and road users in the Al-Kufa city study area as shown in Table 2. The sample size was obtained using Equation 1 [20]:

\[ N = \frac{n}{(1+n(\epsilon))^2} \]
where N: Sample size; n: The total number of households in the relevant area (29,075); and e: The desired level of precision, 0.05 for the 95% confidence level.

Table 1. Volumes of traffic and speeds during the morning rush hour with road characteristics.

| No. of link | Traffic volume (veh/h) | Road width (m) | Building heights (m) | Forestation | Speed (km/h) |
|-------------|------------------------|----------------|----------------------|-------------|--------------|
| 1           | 300                    | 20             | 2                    | 0           | 20           |
| 2           | 1572                   | 40             | 3                    | 0           | 40           |
| 3           | 2904                   | 25             | 3                    | 1           | 60           |
| 4           | 4736                   | 30             | 6                    | 1           | 60           |
| 5           | 4452                   | 40             | 6                    | 0           | 60           |
| 6           | 7512                   | 48             | 6                    | 1           | 40           |
| 7           | 1356                   | 20             | 6                    | 1           | 60           |
| 8           | 1680                   | 30             | 3                    | 1           | 40           |
| 9           | 848                    | 10             | 2.5                  | 1           | 60           |
| 10          | 1324                   | 7              | 2.5                  | 1           | 60           |
| 11          | 1080                   | 12             | 3                    | 0           | 40           |
| 12          | 1080                   | 60             | 3                    | 0           | 60           |
| 13          | 4908                   | 40             | 2                    | 1           | 80           |
| 14          | 4908                   | 40             | 2                    | 1           | 80           |
| 15          | 4908                   | 40             | 2                    | 0           | 80           |
| 16          | 4908                   | 40             | 3                    | 0           | 80           |
| 17          | 2232                   | 30             | 2.5                  | 0           | 40           |
| 18          | 2232                   | 30             | 2.5                  | 1           | 40           |
| 19          | 1080                   | 30             | 3                    | 0           | 60           |
| 20          | 3072                   | 45             | 3                    | 1           | 40           |
| 21          | 3072                   | 45             | 3                    | 1           | 40           |
| 22          | 2964                   | 48             | 6                    | 1           | 40           |
| 23          | 2964                   | 48             | 6                    | 1           | 40           |
| 24          | 4736                   | 30             | 3                    | 0           | 60           |
| 25          | 1356                   | 30             | 3                    | 1           | 60           |
| 26          | 1680                   | 20             | 3                    | 0           | 40           |
| 27          | 848                    | 10             | 2.5                  | 1           | 60           |
| 28          | 2784                   | 30             | 3                    | 1           | 40           |
| 29          | 700                    | 7              | 3                    | 1           | 60           |
| 30          | 700                    | 7              | 3                    | 1           | 60           |
| 31          | 4476                   | 30             | 2.5                  | 0           | 40           |
| 32          | 1620                   | 10             | 2.5                  | 0           | 30           |
| 33          | 2784                   | 30             | 3                    | 1           | 40           |
| 34          | 1050                   | 30             | 3                    | 1           | 40           |
| 35          | 2000                   | 6              | 2.5                  | 1           | 70           |
| 36          | 2000                   | 3              | 2.5                  | 1           | 40           |
| 37          | 1920                   | 30             | 3                    | 0           | 30           |
| 38          | 1920                   | 30             | 3                    | 0           | 30           |
Table 2. The roadside questionnaire

| No. | Vehicle Alarm% | Nearby building % | Intersections % | Roads % | Wheel conditions% |
|-----|----------------|-------------------|-----------------|---------|------------------|
| 39  | 1056           | 25                | 3               | 0       | 30               |
| 40  | 1056           | 25                | 3               | 0       | 30               |
| 41  | 1296           | 20                | 3               | 0       | 40               |
| 42  | 1572           | 30                | 3               | 0       | 40               |
| 43  | 300            | 60                | 2.5             | 1       | 20               |
| 44  | 300            | 60                | 2.5             | 1       | 20               |
| 45  | 300            | 60                | 2.5             | 1       | 20               |
| 46  | 1296           | 20                | 3               | 0       | 40               |
| 47  | 1200           | 30                | 3               | 0       | 40               |
| 48  | 1248           | 40                | 3               | 1       | 60               |
| 49  | 3564           | 30                | 6               | 0       | 30               |
| 50  | 1644           | 20                | 3               | 0       | 40               |
| 51  | 3564           | 30                | 6               | 0       | 30               |
| 52  | 3168           | 30                | 6               | 0       | 30               |
| 53  | 2000           | 15                | 2.5             | 1       | 60               |
| 54  | 1056           | 9                 | 2.5             | 0       | 60               |
| 55  | 2000           | 30                | 3               | 1       | 70               |
| 56  | 2000           | 30                | 2.5             | 1       | 60               |
| 57  | 2140           | 10                | 2.5             | 0       | 30               |
| 58  | 2000           | 10                | 3               | 1       | 70               |
| 59  | 2000           | 7                 | 3               | 0       | 70               |
| 60  | 2000           | 7                 | 3               | 0       | 70               |
| 61  | 2000           | 30                | 3               | 1       | 60               |
| 62  | 2000           | 30                | 2.5             | 0       | 70               |
| 63  | 2000           | 9                 | 2.5             | 0       | 60               |
| 64  | 2000           | 30                | 2.5             | 0       | 70               |
| 65  | 1248           | 30                | 3               | 1       | 40               |
| 66  | 5180           | 60                | 3               | 1       | 40               |
| 67  | 1824           | 30                | 6               | 0       | 30               |
| 68  | 1080           | 60                | 3               | 0       | 60               |
| 69  | 4908           | 40                | 3               | 1       | 80               |
6. Pollution with carbon monoxide (CO)

In this study, the pollution rate caused by congestion in the city streets was calculated using regression equations; these were used to determine the emissions rate of the vehicles on the Kufa roads based on the volume of traffic. Other factors that contributed to these calculations were the speed of traffic flow, the height of neighbouring buildings, and the presence or absence of afforestation. The results are illustrated in Table 3.

Equation 2 presents [18] the model used to calculate the emissions rates on Al-Kufa city network links based on the maximum acceptable value of air pollution with carbon monoxide (CO) being equal to 35 ppm.

\[
Y = 35.087 + 0.659X_1 - 0.379X_2 + 0.411X_3 - 0.593X_4 \ldots \ldots \ldots \ldots \ldots (2)
\]

where

Y: The pollution value of CO in ppm,

\( X_1 \): Equivalent environmental traffic volume for a passenger car at average speed.

\[
X_1 = \frac{V \times (\%PCU + \frac{1}{2}\%HV)}{avg \ speed} \ldots \ldots \ldots \ldots (3)
\]

V: Total volume of traffic on the street in one hour,

\% PCU: The proportion of traffic comprised of private cars,

\% HV: The proportion of traffic comprised of large and medium cars,

\( X_2 \): Roadway average width (m),

\( X_3 \): Average height of adjacent buildings, and

\( X_4 \): Afforestation dummy (1 for greenery and 0 for no greenery).

7. Results and discussions

Table 3 shows the final results for the types and proportion of gases polluting the environment for each link as compared with the EPA (2009) limits in order to determine the percentage of encroachment of polluting gases in these areas. By applying the relevant equation, it was found that only 22 links had acceptable emission rates. Figure 3 shows the pollution results from the TransCAD program for the current year.

Noise levels for all city streets are also shown in Table 3, indicating that very few roads were within the specifications provided by the Ministry of the Environment; Figure 4 shows the noise results from the TransCAD program for the current year (2020).
The questionnaire was structured to offer a variety of questions and choices to help define and explain the issues associated with vehicular operation and to help determine the weights and levels of pollution problems, including noise pollution caused by the impact of air on the front of vehicles and the noise generated by tires and road surfaces. Such factors combined to limit the efficiency of the road use in the road network and intersections in the study area, and the significance of this questionnaire is that it permitted an initial classification of the variables required as part of the measurement of traffic in light of the negative effects of pollution as well as the risks of traffic accidents.

The results of the analysis of the questionnaire data are offered in Table 4.

Table 3. Noise level and emissions rates derived from the regression equations

| No. of link | Sound level (dB) | CO (ppm) | No. of link | Sound level (dB) | CO (ppm) |
|------------|------------------|----------|------------|------------------|----------|
| 1          | 35               | 35       | 36         | 82               | 43       |
| 2          | 75               | 33       | 37         | 78               | 47       |
| 3          | 73               | 41       | 38         | 78               | 47       |
| 4          | 73               | 45       | 39         | 72               | 41       |
| 5          | 73               | 54       | 40         | 72               | 41       |
| 6          | 78               | 70       | 41         | 45               | 40       |
| 7          | 70               | 37       | 42         | 75               | 37       |
| 8          | 74               | 35       | 43         | 65               | 20       |
| 9          | 73               | 34       | 44         | 54               | 20       |
| 10         | 75               | 38       | 45         | 35               | 20       |
| 11         | 74               | 38       | 46         | 45               | 20       |
| 12         | 70               | 20       | 47         | 78               | 35       |
| 13         | 63               | 37       | 48         | 72               | 26       |
| 14         | 60               | 37       | 49         | 81               | 58       |
| 15         | 80               | 38       | 50         | 80               | 38       |
| 16         | 83               | 38       | 51         | 81               | 58       |
| 17         | 82               | 44       | 52         | 83               | 54       |
| 18         | 82               | 43       | 53         | 80               | 37       |
| 19         | 78               | 38       | 54         | 85               | 37       |
| 20         | 85               | 37       | 55         | 78               | 30       |
| 21         | 83               | 37       | 56         | 70               | 31       |
| 22         | 83               | 36       | 57         | 79               | 53       |
| 23         | 83               | 36       | 58         | 73               | 38       |
| 24         | 73               | 50       | 59         | 81               | 40       |
| 25         | 70               | 37       | 60         | 80               | 40       |
| 26         | 74               | 35       | 61         | 85               | 31       |
| 27         | 73               | 34       | 62         | 82               | 31       |
| 28         | 77               | 45       | 63         | 80               | 37       |
| 29         | 78               | 35       | 64         | 82               | 31       |
| 30         | 77               | 35       | 65         | 72               | 26       |
| 31         | 77               | 48       | 66         | 75               | 50       |
| 32         | 81               | 48       | 67         | 82               | 35       |
| 33         | 77               | 45       | 68         | 70               | 20       |
| 34         | 75               | 38       | 69         | 83               | 39       |
According to the roadside survey questionnaire, as outlined in Table 4:

- The key sources of noise in the study area were the surfaces of the lanes, at roughly 44%, due to a lack of maintenance of the surface of the pavement within the network.
- The roads explained high noise areas by about 41%.
- The main reason for high noise levels was vehicle alarms, at about 39%.

Figure 3. Results for CO pollution in 2020.
Figure 4. Results for noise pollution in 2020.

Table 4. Results of the roadside questionnaire at main streets (links and nodes).

| In which areas are noise levels high? | What is the level of noise on the road? | What is the source of noise on the road? |
|--------------------------------------|--------------------------------------|--------------------------------------|
| Nearby building %                   | Intersections %                      | Roads %                              |
|                                     | Low %                                | Medium %                             | High %                                |
|                                     | Air shattering %                     | Road surface %                       | Wheel of the vehicle                  | Motor vehicle% |
| 28.87                               | 30.17                                | 4                                    | 0                                     | 52.2             | 47                        |
|                                     | 10.34                                | 44                                   | 8.2                                   | 37.5                          |

The main reasons for the high levels of traffic noise are:

Main streets: Vehicle alarm %, Motor vehicles %, Road surface %, Wheel conditions %

| Road conditions %              |
|-------------------------------|
| 38.9                          |
| 19.5                          |
| 24.67                         |
| 16.91                         |

In light of the findings, a few improvements can be suggested to reduce the levels of noise and pollution in the city [21]:

A. Encouraging public transportation by scheduling buses and trams more frequently and effectively.
B. Constructing boulevard roads to encourage walking, providing protected and shaded sidewalks to counteract the harsh weather in Iraq.
C. Applying a modern public transportation system and encouraging the use of electric vehicles.

8. Conclusions and recommendations
The main points of this study are noted below:
1. Under existing traffic conditions, the road network and intersections have a relatively low degree of sustainable activity, reflecting extremely low performance in some parts of the system, especially in the second and third sectors.
2. The Kufa network suffers from serious noise pollution. The results show that all main streets in the city have high noise measurements, particularly Kufa-Najaf street and the Airport street, where the traffic flow is the highest in the network.
3. To mitigate noise and pollution levels, effective public transportation systems and electric vehicles should be immediately implemented as significant solutions.

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