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Spatial Analysis of Social Infrastructure Facilities Exposed to High Traffic Noise in Urgench City Using GIS

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ABSTRACT

Traffic noise is one of the most significant environmental health hazards in rapidly growing cities, and its effects are most harmful in sensitive social institutions such as schools, preschools, healthcare facilities and universities. In Uzbekistan, the expansion of urban road networks has outpaced the spatial assessment of these institutions with respect to acoustic exposure. The aim of this study was to identify and spatially evaluate the social infrastructure facilities of Urgench, the administrative centre of the Khorezm Region, that are located within zones of elevated traffic noise. Official municipal statistics on public educational and healthcare institutions were combined with a geospatial model built at a scale of 1:25,000 from OpenStreetMap vector data. The urban road network was treated as the principal line source of noise, and ten concentric multi-ring buffer zones (500–5,000 m at 500 m intervals) were generated around the high-volume central traffic node. Facilities were digitised, classified by function and assigned to buffer zones through spatial overlay. The city operates 45 general education schools, 22 preschool organisations, 35 healthcare facilities and 4 higher education institutions. In total, 112 facilities were identified within the adverse acoustic domain; approximately 75% of them lie within the 500–1,500 m central core, where arterial corridors and major intersections concentrate traffic, whereas only about 10% are found in the peripheral 4,000–5,000 m zone. Although social infrastructure in Urgench is quantitatively adequate, its spatial arrangement exposes most institutions to chronic acoustic stress. The results provide a scientific basis for delineating acoustic discomfort zones and support targeted measures, including noise barriers, green buffer belts, traffic calming and mandatory setbacks for new facilities in the city master plan.

Introduction

Rapid urbanisation and rising intra-urban mobility have led to severe traffic congestion across modern road networks. This process has intensified one of the most pressing challenges of contemporary urban ecology and planning: acoustic pollution. According to the World Health Organization (WHO), environmental noise is among the leading environmental risks to health in Europe, and road traffic is its dominant source [1, 2]. For road traffic noise, the WHO recommends that average exposure be kept below 53 dB Lden and night-time exposure below 45 dB Lnight, because levels above these thresholds are associated with adverse health effects [1].

The harmful impact of noise is particularly acute in sensitive social infrastructure facilities general education schools, preschool organisations, healthcare facilities and higher education institutions which by their function require continuous acoustic comfort and sanitary-ecological stability. Empirical research shows that chronic exposure to traffic noise impairs reading comprehension, memory, attention and information processing in children [3–6]. In healthcare settings, noise disturbs sleep, raises physiological stress and is linked to cardiovascular risk, which can prolong patient recovery [3, 7]. In Uzbekistan, permissible noise levels for residential areas and public buildings are regulated by the sanitary rules and norms SanR&N 0267-09 [8]. The rational spatial distribution of social facilities relative to noise sources is therefore a direct determinant of public health and of the intellectual capacity of society.

Geographic Information Systems (GIS) function as an indispensable Spatial Decision Support System (SDSS) for identifying and resolving such environmental conflicts [9]. Beyond cartographic visualisation, GIS tools allow the objective delineation of urban "acoustic vulnerability hotspots" through proximity (buffer) analysis, multi-criteria layer overlay and distance-based coverage modelling [9]. Strategic noise mapping supported by GIS has become a standard instrument of environmental policy, most notably under the European Environmental Noise Directive 2002/49/EC [10, 11].

In rapidly growing cities of Uzbekistan, notably Urgench, the expansion of residential built-up areas and the encroachment of arterial roads upon existing public institutions are proceeding at an accelerated pace. Nevertheless, comprehensive spatial assessments of the exposure of educational and medical facilities to traffic noise remain scarce, and the quantity of facilities is usually evaluated without regard to their acoustic environment. Official data indicate that Urgench currently operates 45 public general education schools, 22 state preschool education organisations, 35 public healthcare facilities (polyclinics and hospitals) and 4 public higher education institutions [12]. Whether these institutions are located in acoustically acceptable environments, however, has not been examined.

Accordingly, the aim of this study is to examine the aggregate statistical parameters of social infrastructure in Urgench, to identify the facilities exposed to elevated traffic noise using GIS techniques, and to evaluate their spatial distribution from urban planning and ecological perspectives. The study addresses three research questions: (1) how are social infrastructure facilities distributed relative to the main traffic corridors of the city; (2) what share of these facilities lies within the zones of highest traffic intensity; and (3) which planning measures can reduce their acoustic exposure.

2. Materials and Methods

2.1. Study area

Urgench is the administrative centre of the Khorezm Region in north-western Uzbekistan, located in the lower reaches of the Amu Darya River. The city has a compact radial–rectangular street layout in which the main arterial streets converge on a central core containing administrative, commercial and educational functions. This configuration concentrates through and local traffic at a limited number of central intersections, which makes the city a suitable case for studying the relationship between traffic intensity and the location of social facilities.

2.2. Data sources

Two groups of data were used. First, official statistical data on the number of public schools, preschool organisations, healthcare facilities and higher education institutions were obtained from the open data portal of the Statistics Agency under the President of the Republic of Uzbekistan for 2023–2026 [12]. Second, vector data on the road network, buildings and points of interest were extracted from the OpenStreetMap (OSM) database [13]. OSM was selected because it is openly licensed, regularly updated and has been shown to provide positional accuracy comparable to official cartographic sources in urban areas [14]. The locations and functions of facilities were checked against the statistical register and corrected where necessary.

2.3. GIS modelling

The analysis was carried out in [GIS software and version, e.g., ArcGIS 10.8 / QGIS 3.x] and comprised the following stages:

- **Base model.** A geospatial model of the city was established at a scale of 1:25,000 using OSM vector datasets [13].
- **Noise source definition.** The "Urgench city road network" layer was designated as the primary line source of dynamic vehicular noise emissions, with the central node — where the main

arterial streets and the highest-volume intersections converge — treated as the point of maximum traffic intensity.

- **Buffer generation.** Ten concentric multi-ring buffer zones were generated outward from the central high-volume node, from 500 m to 5,000 m at 500 m intervals [9, 13]. The zones were colour-coded from red (500 m) through orange and yellow to green (4,000–5,000 m) to represent a gradient from the highest to the lowest traffic load.
- **Facility mapping and classification.** Social infrastructure facilities were digitised as point features and classified into universities, healthcare institutions, schools, preschool education institutions, academic lyceums and colleges, orphanages, and cultural and recreational facilities.
- **Spatial overlay.** A point-in-polygon overlay was used to assign each facility to a buffer zone and to count the number and share of facilities per zone. The focal research objects, marked with blue arrows on the map, were isolated as target points representing the highest noise vulnerability (Figure 1).

2.4. Analytical approach

Aggregate statistical indicators were first compared with the spatial pattern produced by the model, in order to move from macro-level descriptive statistics to targeted spatial assessment. Buffer distance from the central traffic node was used as a proxy for traffic-noise load. A full acoustic propagation model, such as the CNOSSOS-EU method [15], was not applied at this stage; the analysis is therefore a screening-level assessment intended to prioritise facilities for subsequent field measurement.

3. Results

3.1. Aggregate statistical indicators

Table 1 summarises the official inventory of public social infrastructure in Urgench. Schools form the largest group (42.5%), followed by healthcare facilities (33.0%) and preschool organisations (20.8%). From a purely quantitative standpoint, the network of institutions is consistent with the general demographic needs of the city.

Table 1. Public social infrastructure facilities in Urgench (official statistics [12])

Facility category	**Number**	**Share, %**
General education schools	45	42.5
State preschool education organisations	22	20.8
Healthcare facilities (polyclinics and hospitals)	35	33.0
Higher education institutions	4	3.8
Total	**106**	**100.0**

3.2. Spatial distribution of facilities

The geospatial model (Figure 1) shows that facilities are not distributed evenly across the city but cluster along the principal arterial corridors and around the central intersections. Schools, preschools and healthcare institutions are concentrated in the red and orange buffer zones, while the outer yellow and green zones contain mainly residential blocks with sparser institutional coverage. The focal research objects (blue arrows) are located directly beside major streets in the north-western part of the central core and in the inner orange zone.

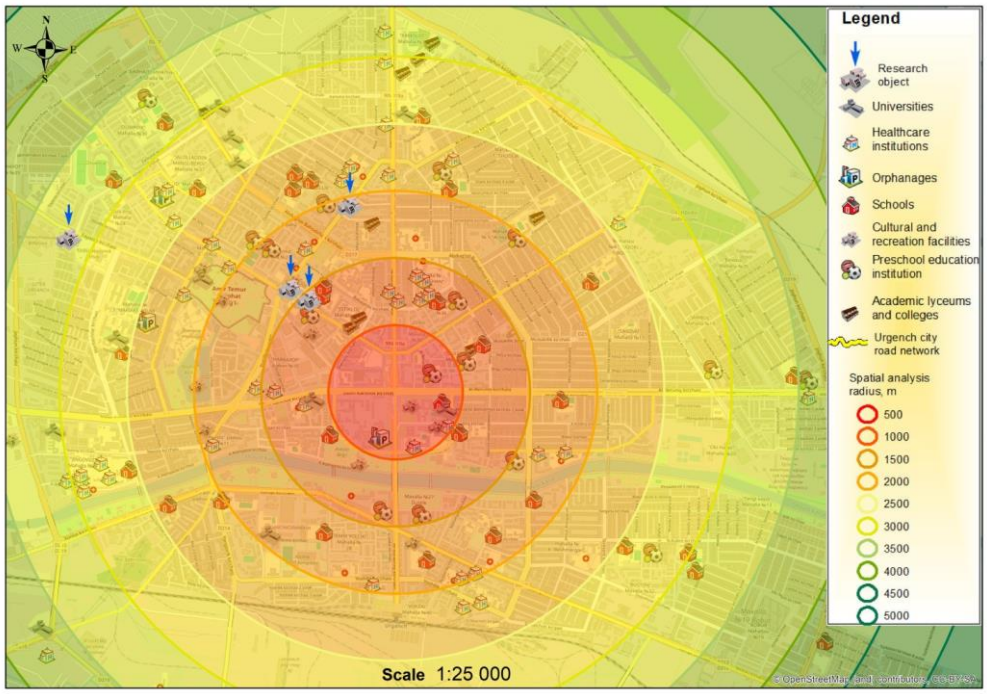

Figure 1. Spatial distribution of public social infrastructure facilities along high-traffic corridors in Urgench and multi-ring buffer zones (500–5,000 m) around the central traffic node. Base map: © Open Street Map contributors, CC-BY-SA.

3.3. Distribution of facilities by buffer zone

Overall, 112 facilities were identified within the adverse acoustic domain. Their distribution across the buffer zones is shown in Table 2 and reveals three distinct patterns.

Table 2. Distribution of social infrastructure facilities by traffic-noise buffer zone

Zone	**Radius, m**	**Map colour**	**Share, %**	**Approx. number***
Central core	500–1,500	Red – dark orange	≈75	≈84
Intermediate belt	2,000–3,500	Orange – yellow	≈15	≈17
Periphery	4,000–5,000	Green	≈10	≈11
Total	**500–5,000**	**–**	**100**	**112**

**Approximate numbers are calculated from the zone shares; the share of the intermediate belt is derived as the remainder.*

Corridor-adjacent concentration. Relative to the total building stock, a disproportionately large share of facilities is located directly along arterial corridors and at major intersections. The largest subset of the exposed facilities consists of hospitals, secondary schools and preschools [12].

Central core exposure (500–1,500 m). Facilities located in the red (500 m) and dark orange (1,000–1,500 m) zones account for approximately 75% of all facilities in the noise-affected domain. Schools and preschools that directly flank the main urban axes therefore operate under conditions of chronic acoustic discomfort.

Peripheral distribution (4,000–5,000 m). The peripheral green zones contain far fewer institutions (about 10% of the total). Even here, however, several educational facilities situated directly along external transit corridors remain exposed to elevated traffic noise.

4. Discussion

The results show a clear mismatch between the quantitative adequacy and the spatial quality of social infrastructure in Urgench. While the number of schools, preschools and healthcare facilities

corresponds to municipal needs (Table 1), three quarters of the facilities in the noise-affected domain are concentrated in the central core, where traffic flows are heaviest. This pattern is typical of cities that developed around a historical centre: institutions were sited for accessibility, and the traffic load on adjacent streets subsequently grew with motorisation.

The concentration of schools and preschools near arterial streets is of particular concern. International studies have shown that children attending schools exposed to road traffic noise perform worse in reading comprehension and memory tasks, and that these effects persist after adjustment for socio-economic factors [4–6]. Children are especially vulnerable because their cognitive and language skills are still developing and because they spend a large proportion of the day in school buildings [5]. Likewise, the location of hospitals and polyclinics along busy corridors may hinder patient recovery through sleep disturbance and stress-related cardiovascular responses [3, 7]. The facilities identified in the central core should therefore be regarded as priority objects for acoustic protection.

From a methodological perspective, the study confirms that GIS-based buffer analysis built on open OSM data is an efficient screening tool for cities where official noise maps are not available [9, 14]. It allows planners to move quickly from aggregate statistics to a list of specific, spatially located facilities. Similar approaches underpin strategic noise mapping in the European Union, where GIS is used to estimate the number of people and sensitive buildings exposed to noise [10, 11].

The results should also be interpreted in the light of several limitations. First, the concentric buffers around the central node represent a gradient of traffic intensity rather than actual sound levels; in reality, noise from a road decreases sharply within the first 100–300 m from the carriageway, so facilities in outer zones that front a busy road may be more exposed than facilities in the core that are shielded by buildings. Second, no field noise measurements or traffic counts were used to calibrate the model. Third, OSM data may contain omissions or classification errors. Future work should therefore (a) apply linear buffers of 50, 100 and 200 m along each arterial road, (b) carry out on-site measurements of LAeq and Lden near the identified facilities in accordance with SanR&N 0267-09 [8], and (c) use a standard acoustic propagation model such as CNOSSOS-EU [15] to produce a calibrated noise map of the city.

Despite these limitations, the findings have direct practical value for urban planning. They indicate where noise mitigation will yield the greatest health benefit and provide an evidence base for revising the city master plan in line with national planning norms ShNQ 2.07.01-03 [16].

5. Conclusions

Integrating aggregate statistical data with GIS-based spatial modelling shows that, although social infrastructure in Urgench is quantitatively adequate, its spatial arrangement has notable acoustic deficiencies. About three quarters of the identified facilities lie in the 500–1,500 m central core, and many educational and medical institutions border major transit arteries and operate under constant acoustic stress. To create a healthy urban environment and ensure acoustic comfort, the following planning measures are proposed:

- installing engineered noise barriers (acoustic absorption screens) along the boundaries of schools, preschools and universities located in the peak noise zones;
- establishing multi-row green buffer strips of dense trees and shrubs around facilities adjacent to arterial roads to act as natural sound barriers;
- implementing physical traffic-calming measures (speed tables, raised crosswalks), lower speed limits and horn restrictions on road segments bordering sensitive institutions;
- upgrading the sound insulation of existing buildings (noise-insulating windows and façades) for facilities that cannot be relocated;

- introducing mandatory setback provisions in future municipal master plans so that new social facilities are sited at least 50–100 m from primary arterial roads, within acoustically shielded zones [16].

The proposed GIS approach can be readily transferred to other cities of Uzbekistan and, once supplemented with field measurements, can serve as the basis for a city-wide acoustic zoning system.

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