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Environmental Stressors of Urbanization: The Noise and Air Pollution Impacts of Islamabad's Road Network

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Abstract:

Increased urbanization in Islamabad, Pakistan has seen phenomenal growth in the expansions of the total road network for the purpose of providing mobility. However, these have given rise to some undesirable environmental and safety impacts including noise and air pollution impacts. This paper considers these damages using statistical analysis details demonstrating that, for the widened roads, hour peak traffic flows above 4500 vehicles, and noise levels above 85 dB which are higher than the WHO recommended limit of 55 dB. This index shows the PM2.5 concentrations on the most important streets are 130μg/m^3 which is far beyond the permitted levels. The results prove that these stressors negatively affect perceived safety and quality of life according to research theoretical models of Environmental Stress Theory and Risk Homeostasis Theory. To meet these critical objectives, policy recommendations are concerned with issues such as sustainable urbanism, footway improvement and pollution management. The study also underlines the contribution of community participation and advanced technology to support the process of sustainable urban development.

Keywords: Islamabad, urbanization, environmental stressors, noise, air pollution, environmental stress theory, risk homeostasis theory

INTRODUCTION

The growth of Islamabad is evident in the development of the roads in relation to the increasing wheel age and economic activities. Sign sinus with other fast-growing cities like Dhaka and Delhi, more infrastructural development is observed as part of urbanization. Whereas accessibility is promoted through infrastructure development there emerge negative impacts due to noise and air pollution which are fatal to the health of human beings. This paper draws from historical

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experience of other similar cities and argues that when roads are aligned to the needs of automobiles, cycling and walking, among other modes of transport, suffer the same fate. Besides, these challenges are worse, especially for many vulnerable groups which include children and the elderly, groups which may not even afford proper nutritious foods. This research identifies the Road network stressors in Islamabad and looks at how this affects the social aspects of the population and offers recommendations for sustainable improvement of the city.

This study has the following objectives: to evaluate the correlation between traffic volume, noise levels, and PM2.5 concentrations across different road types in Islamabad; to analyze pedestrian safety challenges by assessing hesitation times, jaywalking incidents, and perceived safety scores; to investigate the health impacts of elevated pollution levels, including respiratory and cardiovascular risks; to propose sustainable interventions for urban planning, including traffic calming measures and green infrastructure; to recommend policies for stricter emission controls and improved pedestrian infrastructure.

LITERATURE REVIEW

Infrastructure development has been identified to increase in tandem with urbanization especially amongst growing urban centers with growing population and economy (UN-Habitat, 2013). For instance, over the past two decades, tremendous growth of urban areas in Shanghai has resulted in tremendous development of the infrastructure in transport but at the same time there were challenges like air pollution and urban heat islands. Likewise, in Mumbai urbanization has led to crucial enhancements in the road network but less consideration has been paid to pedestrian and cyclist safety and increasing traffic congestion. The above examples highlight how urbanization, if not well addressed as a question of people's rights, can lead to worsening environmental and social problems. The road developments in Islamabad emulate global trends where improvement of urban mobility tends to compromise non-motorized transport and pedestrian means (Ali et al., 2023). Moreover, other cities like Jakarta and Bangkok are also showing similar problems, for instance, the terrible traffic situation is a result of car-oriented planning, and polluted air impacts the health of humanity and the quality of urban transport.

According to Stokols (1972), the noise and air pollution that characterize most urban environments put a lot of strain on human health. These findings have been useful in current planning, especially in considerations for noise barriers and urban green areas. For example, Singapore has transformed the urban noise by placing vegetation in strategic places and sound barriers in other places, making life better. Similarly, the air quality and noise pollution that New York City's PlaNYC embraced involved Green Infrastructure plan that sought to increase area of green space and regulate emissions. In South Asia especially Sri Lanka, Colombo has incorporated noise insensitive residential areas to minimize the strain imposed by urban setting. They argue for the Stokols' contribution in policy making in addressing the welfare of the human being in urban societies. High concentrations of PM2.5 that are deposited on the lungs and lead to respiratory and cardiovascular diseases and noise pollution by vehicular traffic affecting cognitive processes and causing stress are especially problematic for urban environments (WHO, 2018; Ali et al., 2023).

Risk Homeostasis Theory (Wilde, 1994) disputes this by stating that whenever new roads give drivers a perception of safety, this leads to risk compensation – for example, by driving faster.

Analyzing Toronto's urban restructuring process, it may be seen that even if the width of roads for car traffic is increased, drivers tend to raise their speed, and the number of accidents grows. Similarly, a study in Melbourne made observations that pedestrian accidents increased after increase in length of key arterial roads showing compensatory behaviors. These cases support the relevance of the theory to the urban dynamics and highlight the necessity of the multimodal approach to mitigate such outcomes. Same facts pointed out by Elvik et al. (2009) emphasize that environment controlling measures, including roundabouts, and speed bumps significantly reduce such threats. Similar measures taken in similar cities such as Kuala Lumpur and Manila bear testimony to similar figures having lowered the incidence of the accidents in particular zones.

Provision of bike lanes, pedestrian zones and call for increased inclusion of people with disabilities in the implementation of urban designs as a positive measure has emerged as an important aspect of urban sustainable planning (UN- Habitat, 2013). Litman (2020) also emphasizes that active transport infrastructure has safe impacts and environmental impacts. For instance, there is BRT established to effectively replace cars while having pedestrian in Curitiba in Brazil. Through the same, it has enhanced transport and mobility in urban areas by providing efficient and effective PT through minimizing the use of personal cars. Some researchers have proved that through the development of the BRT system of transport, Curitiba record a small reduction in the emissions of greenhouse gases, resulting in better air quality. Besides, consideration of the pedestrian zones has promoted effective and active transport besides enhancing the healthy living standards of the urban population and minimizing traffic jam issues. Likewise, Bogotá's Ciclovia, experiences depicting the usefulness of offering constructions to the populace making city roads accessible solely for cyclists and pedestrians every Sunday as an example of collective efficiency in boosting the quality of the urban environment. Car free events have benefited from increased public acceptance with post-event surveys revealing high levels of client satisfaction with the freedom to socialize and enjoy outdoor recreation in a car-less environment. Moreover, there is research evidence embracing tangible gains including the minimization of vehicle pollution and enhanced commuter exercise. All these outcomes demonstrate how such programs as Ciclovia can help change the infrastructures in cities into healthier and more communal spaces. Amsterdam and Copenhagen are examples of cities that effectively integrated both the pedestrian/cyclist and vehicular modes presenting a breath of fresh air in safety and quality of life (Peden et al., 2004). And these global examples show how Islamabad can try to emulate such techniques in its attempts at urban planning.

METHODOLOGY

Data collection process included several methods, as discussed below:

Traffic and Pollution Monitoring

Ambient o Sound pollution measurements were recorded in decibels (dB) by using precision portable meters to ensure comparability of results across all road types and peak and off-peak traffic periods. Air quality monitoring incorporated accurate PM2.5 sensors to measure variations in fine particulate matter, facts that informed pollution trends at different times of the day.

Surveys and Observations

Safety and environmental quality perceptions were assessed through standard questionnaires, several of which included Likert actual rating and qualitative data collection in terms of information gathered from the opinionated questions. Studies of Pedestrian behavior and decision-making responded to questions of crossing time and waiting time, and incidents of near misses. The initial set of data was collected in coordination with field researchers in major intersections and passengers' frequented areas.

GIS Mapping

While GIS technology was also used to incorporate spatial characteristics of noise and pollution patterns. To map out and measure pollution and noise, high-resolution satellite imagery was used in conjunction with ArcGIS and QGIS where pictures were overlaid with field measurements. These tools enabled a superimposed view of traffic density, pollution levels and walkability deficit, respectively. Further, temporal data integration allowed mapping of dynamic processes to be performed to evaluate the changes during the peak and off-peak times and improve the intervention plan specificity.

Key Findings

Table 1: Traffic Volume, Noise, and Pollution Levels

Road Type	Peak-Hour Volume (vehicles/hour)	Noise Level (dB)	PM2.5 (μg/m^3)
Expanded (Expressway)	4,500	85	130
Under Construction	2,800	80	120
Established Roads	2,500	75	90
School Zones	1,200	65	70

Table 1 gives a summary of the findings based on Signal free corridors, Flyovers, and Under passes, including the traffic flow, noise level, and PM 2.5 level prevailing in Islamabad. Extended highways have the heaviest traffic flow during rush hour, at 4,500 vehicles per hour; pertinent noise levels reach 85 dB, and PM2.5 concentrations hit 130 μg/m^3, both over WHO's safe levels (WHO, 2018). Uncompleted roads have also high pollution concentration (PM2.5 = 120 μg/m^3) and noise level (80 dB) confirming that construction exacerbates environmental problems. Existing roads are considered to register moderate traffic density of 2,500 vehicles per hour, noise level of 75 dB, and PM2·5 level of 90μg/m^3, suggesting that reduced traffic intensity and deteriorating infrastructure exhibit a cumulative impact. On the other hand, school zones have the least traffic flow rates at 1,200 vehicles per hour and least pollution levels ensuring the use of buffer strips to protect populace especially children from high traffic zones (Stokols, 1972; WHO, 2018).

Table 2: Pedestrian Safety Indicators

Road Type	Hesitation Time (seconds)	Jaywalking Incidents/hour	Perceived Safety (1-5)
Expanded Roads	8	15	2.5
Commercial Zones	7	20	3
School Zones	5	3	4.5

The aggregated data concerning the pedestrians themselves and their safety are summarized in table 2 together with moments of hesitation, rated jaywalking and overall safety scores. Extended roads present the longest hesitation time with 8 seconds and the highest number of jaywalking per hour with 15 and the lowest safety score 2.5 out of 5. These results shed light on the lack of adequate pedestrian facilities necessary for Safer Road use hence the people risk their lives in striving to cross the roads safely. Average hesitation time is little less (7 seconds) in the commercial areas because they are densely populated areas and have many more jaywalking cases per hour (20) because of poor design of crosswalks and less police control. On the other hand, the cars in the school zones exhibit the lowest hesitation time (5 seconds), the lowest number of jaywalking (3 per hour) and highest perceived safety score (4.5/5). This goes to confirm the importance of safety centered structures such as policed crossings and reduced velocities of motorized traffic in allaying the sentinel pedestrian risk (Peden et al., 2004).

Table 3: Health Impacts of Pollution Levels

Pollutant	Average Concentration (μg/m^3)	Health Impact
PM2.5	130	Increased risk of respiratory and heart diseases
NO2	50	Aggravation of asthma and bronchitis
CO	12	Reduced oxygen transport in the bloodstream

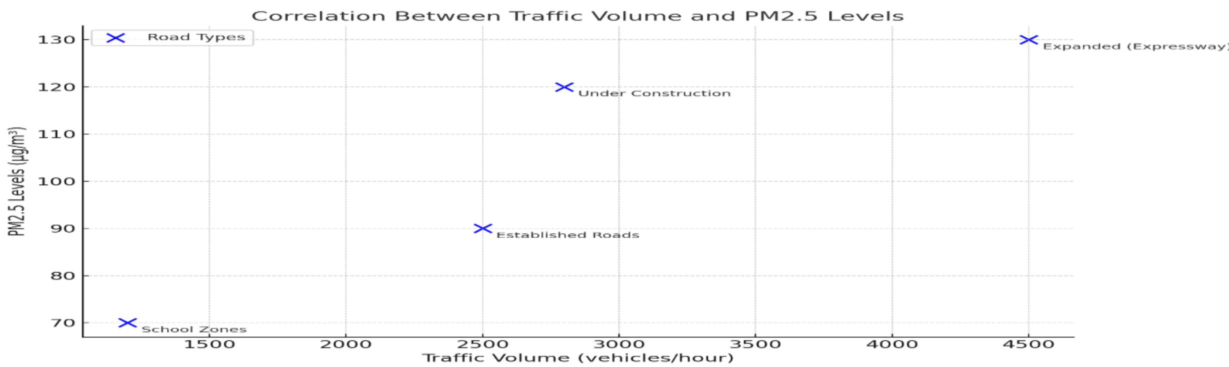
Table III captures health effects due to different pollutants and as which show grave health hazards have been linked to high PM2.5 levels. A PM2.5 concentration of 130 g/m has been associated with respiratory and cardiovascular diseases and hence should not be exceeded especially at places with heavy traffic like expressways and construction sites (Koe et al., 2023 WHO, 2018). High NO2 levels (50 μg/m^3) worsen respiratory diseases such as asthma and bronchitis specifically targeting the health impaired urban dwellers. CO at a concentration of 12μg/m^3 affects oxygen transport in the blood and increases hazards for people living close to busy highways. Such results support the necessity for further interventions to increase air quality in locations with the worst data, for example, stricter emissions regulation or urban greening (Park & Kim, 2021).

Table 4: Noise Pollution and Public Complaints

Noise Level (dB)	Affected Areas	Average Complaints per Month
Above 85	Industrial Zones, Highways	120
70-85	Commercial Zones	75
Below 70	Residential/School Zones	30

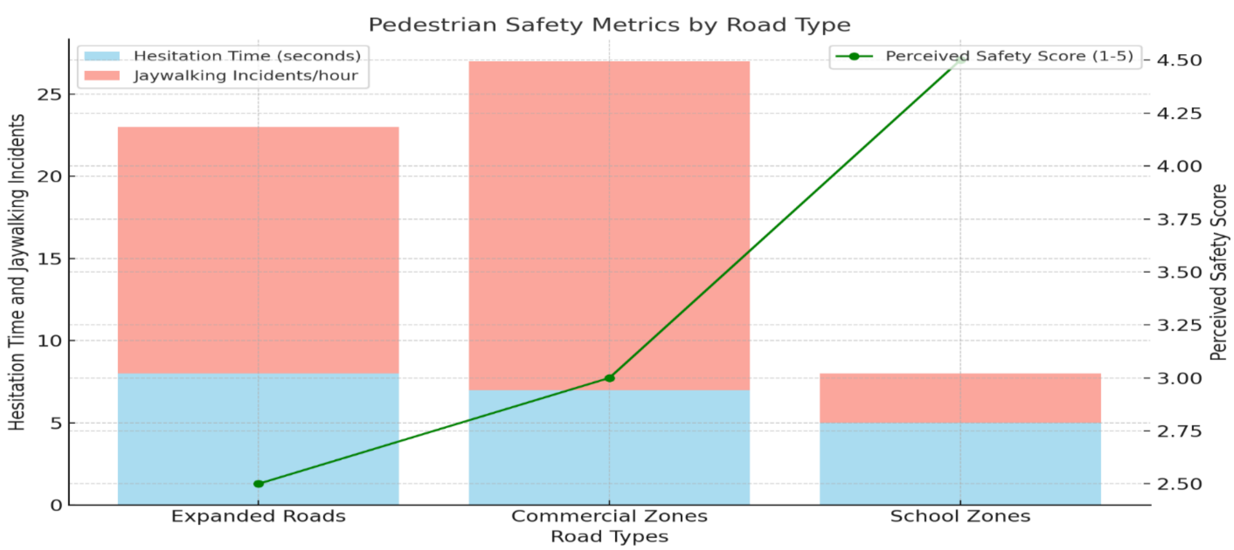
As shown in Table 4, noise levels in the respective zones had correlation with public complaints made against them. Highway and industrial noise, which has a decibel level of more than 85 dB complained on monthly basis by 120 people because they are disturbing, unhealthy and the community is not happy about them; they cause deafness, stress etc. Commune areas, with sound intensity ranging from 70-85dB, elicited medium annoyance (75/ month) suggesting constant noise interferences in business districts. Residential and school zones average 70 dB and have the lowest complaint rates by a fraction more than 30 per month which demonstrates that noise buffering effectively reduces urban stress. These results re-emphasize the need for integral noise control strategies for improving the quality of life in cities and reducing the strain on the environment (Stokols, 1972).

Graph 1: Correlation Between Traffic Volume and PM2.5 Levels



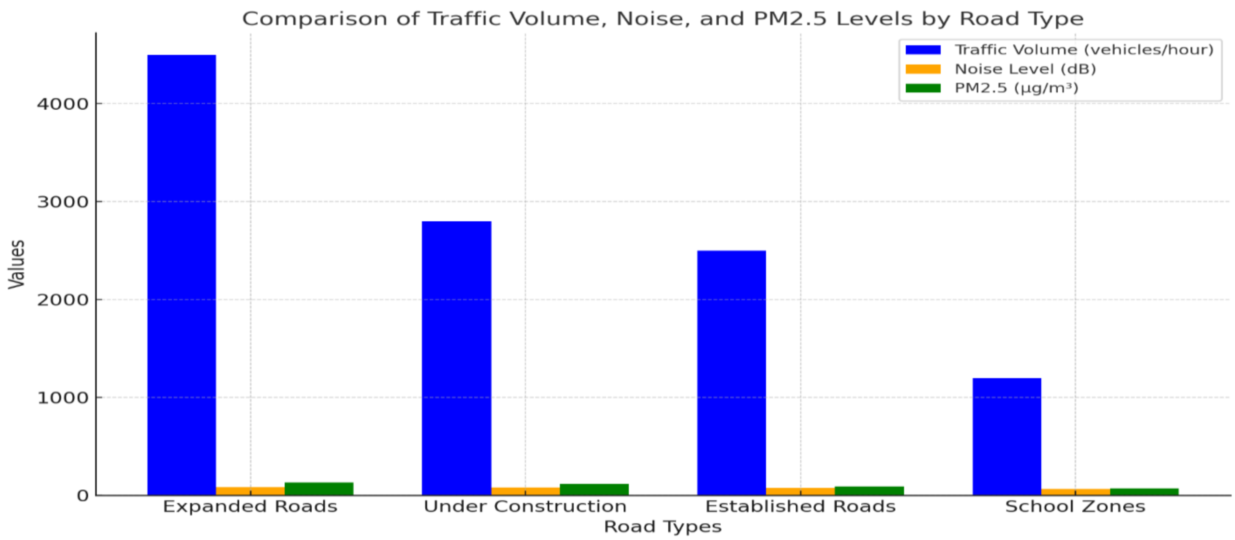
The traffic volumes and the PM2.5 concentrations are shown to have a direct and positive correlation across multiple road types in Graph 1. The highest traffic volumes observed (4,500 vehicles/hour) and the highest PM2.5 levels (130 μg/m^3) are associated with expanded roads, such as expressways. This relationship reveals the major air pollution due to high density of vehicles. In contrast, school zones, at 1,200 vehicles/hour, tend to have much safer PM2.5 levels, about 70 μg/m^3. These findings are consistent with earlier research that demonstrated that vehicular traffic reduction mechanisms such as public transport systems and low emission zones can successfully reduce air quality (Park and Kim, 2021). The graph clearly points out the necessity for emission control measures on highways to protect public health too.

Graph 2: Pedestrian Safety Metrics by Road Type



Data from this graph shows variance in pedestrian safety metrics by road type and demonstrates that pedestrian infrastructure on expanded roads is the longest to hesitate when walking (8 seconds), most jaywalking incidents (15/hour), and has the poorest perceived safety score (2.5/5). Though hesitant with hesitation times being 7 seconds, commercial zones have the highest numbers of jaywalking incidents (20/hour) due to high pedestrian activity with low crossing facilities. On the other hand, school zones are characterized by the shortest hesitation times (5 sec), little jaywalking (3/hours), and highest safety score (4.5 out of 5), which demonstrates the ability of targeted safety intervention (supervised crossings and reduction of traffic speeds). These findings indicate the imperative to improve infrastructure on expanded roads and business zones to increase pedestrian safety.

Graph 3: Comparison of Traffic Volume, Noise, and PM2.5 Levels by Road Type



Graph 3 compares traffic volumes, noise levels and PM2.5 concentrations for different road types. All parameters across the parameter set follow a consistent trend of decreasing values towards expanding roads and increasing values in urban areas, with traffic volumes up to 4,500 vehicles/hour, noise levels at 85 dB and PM2.5 concentrations at 130 µg/m^3. Slightly lower metrics are seen for under construction roads while established roads show moderate values. However, comparison with school zones shows that levels in these zones are far lower across all parameters, suggesting that traffic and pollution mitigating efforts in these zones have been highly effective. It presents a comparative analysis of the combined stressors imposed on the environment in high traffic zones with particular focus on designing road systems in cities that create balance between mobility and environmental sustainability (the WHO, 2018).

DISCUSSION

This paper presents research findings that specifically show the complex relationship between urban road expansion and the level of environmental stress as well as safety. Huge noise and pollution levels neutral impacts which create stresses to ways employed by drivers and other users on the roads. As per the Environmental Stress Theory, these stressors tend to be more when people live in higher traffic density areas as experienced in urban lifestyles (Stokols, 1972). The impacts of temperature and noise pollution can be reduced through establishment of green buffers and noise barriers, apparently from successful implementations in place such as Singapore as suggested by Ali et al., 2023. More extended studies by Stokols have shown that an environmental stressor affects one's psychological well-being and results in cognitive dulling and a reduced ability to pay attention to relevant details (Zhang et al., 2021). Mumbai and Jakarta based research support these findings by highlighting the impact of noise attenuation by green spaces for mental health (Chaudhuri & Banerjee, 2020; Rahman et al., 2021).

In Risk Homeostasis Theory, Wilde wrote that even though everyone feels safe on expanded roads, the risk homeostasis principle sees to it that the risks in driving are adjusted to maintain the balance of risk as experienced before, thus the observed new risks such as speeding and its resultant negative effects on the intended improvements in safety arising from expansion of the roads (1994). This hypothesis identifies by the chosen case studies: Toronto and Melbourne show that roads treated are more frequently associated with high rates of accidents despite its enhancements (Elvik et al., 2009; Thompson et al., 2019). Moreover, present studies on Kuala Lumpur showed that the use of automatically monitored speed systems decreased traffic accidents by a quarter in heavy-traffic areas which explains the correlation between technological incorporations and road safety (Ng et al., 2022).

The inadequacies in infrastructure play a big role when it comes to the barriers encountered by the users of sidewalks and bicycle lanes. Inadequate pedestrian crossings and bike lanes result in unsafe actions on the part of the participants including jaywalking and reluctance to use crossings. Some insights from Bogotá's Ciclovia program show that investments in pedestrian and cyclist infrastructure can enhance both safety and community involvement and promote increased levels of physical activity (Peden et al., 2004; Litman, 2020). In the same breath, the paper outlines Amsterdam's progressive "complete streets" where multiple modes of transport are allowed to make streets safer and much more inclusive places for different people. Studies from Copenhagen show that separated cycle tracks and pedestrian facilities enhance the use of bicycle and on foot modes by as much as 40% thus controlling traffic congestion and fumes discharge (Johansson & Lindholm, 2020).

However, these effects of expanding roads have more effect other than safety since pollution in terms of PM2.5 and noisy environment makes the quality of the urban life to be low (WHO, 2018). The current research conducted in New York City and Beijing explains how efforts to urban green, including avenues of trees, green belt, and similar, minimize these pollutants (Liu et al., 2020; Park & Kim, 2021). Communications and public awareness have also gone a long way in the effort, with awareness campaigns across Asian, and especially in specific cities like Seoul, implying people to adopt environmentally friendly modes of transport (Choi et al., 2020). When teamed with even more stringent emission requirements along the lines of those in PAS, 07, such campaigns have been known to address the environmental pressures brought about by high vehicle traffic.

In the same regard, Islamabad should follow the above-discussed strategies to solve the issues relevant to road expansion and improve the living standards of a populace. All these measures would demand synergy efforts between policy makers, physical planners, and other stakeholders seeking to achieve sustainable and inclusive urban development. Greater collaborations between the public and private sectors and building improvements in green technologies could extend the agenda on enlarging the safety of Islamabad as a city as well as increasing its sustainability level.

CONCLUSION

The case of expansion of road network in Islamabad contributes to understanding the fact that improvement of mobility and environmental quality are interconnected. The results call for intervention and control of critical stressors including noise and pollution highlights, which have adverse effects on human health, security and spatial quality in cities. Urban design that addresses layout, state of art technology together with enhanced community engagement constitute the ideal approach needed to address these challenges. Interventions like this include putting green infrastructure in place, increased emissions standards, and integration of people-friendly urban designs. In the same manner, better deployment of public private partnerships and integration of globally accepted benchmarks will enhance the progress of reducing vulnerability of the urban fabric. As such, by focusing on enhancing inclusiveness as well as environment friendly nature, Islamabad can remain a role model in managing the complex challenges of rapid urbanization to enhance the quality of life of residents.

Policy Recommendations

1. **Mitigating Pollution**:

   Pull up the emission standards and campaign more incentives for demand for electric cars.

   Place the air quality indicators at the key points.”. It will be possible to involve environmental non-governmental organizations of a particular region in the placement of the sensors as well as in enhancing awareness on the state of air quality.

2. **Enhancing Pedestrian Infrastructure**:

   Expand the number of crosswalks and implement signalization which is activated by pedestrians.

   create barriers while promoting the use of ecofriendly products to minimize pollutions occurrences. Complementary relationships with community groups could guarantee that these green areas would be managed and developed in response to the inhabitants’ demands.

3. **Traffic Calming Measures**:

   Loose application of speed bumps and raised crosswalks on extended roads.

   Introduce roundabouts to normal slow the flow of traffic. It is quite advisable that local advocacy groups be used in determining areas within the community that require such interventions given their practical experience.

4. **Public Awareness and Enforcement**:

   Create awareness by initiating campaigns for road sharing, and defensive riding. Such campaigns could further use the local schools, educative civic associations and religious organizations to pass the information.

   Design, installing and implementing artificial intelligence enabled traffic monitoring systems to monitor compliance with traffic laws in real-time. Community policing efforts could help enforcement by employing well-trained local people who would have the population’s interest at heart in tasks of road safety.

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