Journal of Air Pollution and Health (Winter 2024); 9(1): 41-58

Original Article

Available online at http://japh.tums.ac.ir

Analysis of in-vehicle air quality and load factor as environmental and social dimensions of sustainable urban mobility: A case study from Kathmandu valley, Nepal

Pooja Bhusal[1,*], Suman Man Shrestha[1], Narayan Babu Dhital[2], Gauri Shankar Bhandari[3], Bhupendra Das[4], Rishav Pandit[5]

[1] Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal
[2] Patan Multiple Campus,Tribhuvan University, Kathmandu, Nepal
[3] Resources Himalaya Foundation, Naya bato, Lalitpur, Nepal
[4] Nepal Energy and Environment Development Services (NEEDS), Lalitpur, Nepal
[5] Institute of Agriculture and Animal Science, Tribhuvan University, Kathmandu, Nepal

ARTICLE INFORMATION

Article Chronology:
Received 19 November 2023
Revised 28 January 2024
Accepted 03 March 2024
Published 29 March 2024

Keywords:
In-vehicle air quality; Particulate matter (PM); Carbon dioxide (Co$_2$); Sustainable urban mobility

CORRESPONDING AUTHOR:

poojabhusal.env@gmail.com
Tel: (+977 1) 4332147
Fax: (+977 1) 4332147

ABSTRACT

Introduction: Assessing in-vehicle air pollution and load factor is crucial in developing countries like Nepal within the environmental and social aspects of sustainable urban mobility.

Materials and methods: In this study in-vehicle air quality of public vehicles in Kathmandu valley was monitored for three road sections based on vehicle density i.e. Ring Road Section (RRS), Urban Commercial Route 1 (UCR1), and Urban Commercial Route 2 (UCR2) using Air Visual Pro N1 Model for which validationand was done with reference Particulate Matter (PM) values obtained from the GRIMM EDM 180 analyzer. The quantitative count method was used to sample passenger load. Particulate Matter (PM_1, $PM_{2.5}$, PM_{10}) were monitored along with indoor-outdoor ratio for $PM_{2.5}$ to know the relationship between indoor and outdoor air quality.

Results: A higher positive correlation between $PM_{2.5}$ and PM_{10} showed common sources of pollution such as road dust, and vehicle exhaust and a ratio study between them showed the dominance of coarser particles in both ambient and in-vehicle environments. RRS recorded the highest PM_{10} and $PM_{2.5}$ exposure, possibly due to the inadequate road conditions from Kalanki to Gongabu and loose sediment deposition from roadside activities. A significant difference is observed for peak and non-peak hours due to the difference in mobility of vehicles on two different hours. Higher load factors on UCR1 and UCR2 showed the higher transportation demand on urban commercial sections for both weekdays and weekends in comparison to RRS.

Conclusion: Both in-vehicle air quality and load factor for sections under study were not satisfactory and cannot be counted under sustainable urban mobility practices.

Introduction

Many cities worldwide face significant air quality issues, which have garnered increased attention in the last decade where the primary factors contributing to poor air quality are the growing populations in metropolitan areas and

Please cite this article as: Bhusal P, Shrestha SM, Dhital NB, Bhandari GS, Das B, Pandit R. Analysis of in-vehicle air quality and load factor as environmental and social dimensions of sustainable urban mobility: A case study from Kathmandu valley, Nepal. Journal of Air Pollution and Health. 2024;9(1): 41-58.

the changes in land use resulting from urban expansion [1]. Ambient air pollution exhibits temporal and regional variations .The migration to cities, particularly in emerging nations, is primarily a consequence of profound structural changes [2]. The Kathmandu valley experiences a rapid increase in air pollution due to human activities which leads long-term exposure to deteriorating air quality heightens the risk of developing Non Communicable Diseases (NCDs) like cancer, heart disease, and respiratory illnesses. Moreover, short-term exposure can lead to allergies and respiratory disorders [3]. Air pollution is a significant concern due to its impact on air quality, human exposure, public health, climate change, and visibility reduction [4].

The global population is at risk of health issues due to the poor quality of ambient air specific to populations such as children, the elderly, and individuals with pre-existing cardiovascular or respiratory conditions, are particularly vulnerable to negative health effects [5, 6]. Research has shown that children are especially susceptible to respiratory problems and allergies resulting from air pollution due to their developing bodies, increased physical activity as different physiological and behavioural factor [7].

The IQAir, a real-time air quality data platform, specializes in air purification solutions, protection against airborne pollutants, and air quality monitoring [8]. According to IQAir, the $PM_{2.5}$ level in Kathmandu exceeded the acceptable limit of 151, reaching 176 per hour. The Global Burden of Disease Study has estimated that both household air pollution from solid fuels and ambient Particulate Matter ($PM_{2.5}$) contribute to over 3 million deaths annually worldwide. The increasing population and the resulting transportation demands have burdened the public transportation system. The population has been growing at a rate of 4.32% per year, while motorization has increased by 12% per year in Kathmandu Valley. However, the modal share of public transport has remained stagnant [9-11].The current public transportation system in the Kathmandu valley is characterized by its disorganization, unreliability, pollution discomfort. With the increasing occurrence of traffic congestion issues, it has become crucial to encourage more people to use public transport. Over the past 15 years, the number of vehicles in the Kathmandu valley has experienced a rapid increase. Registered automobiles went from 24,003 in 2000/1 to 7, 79,822 in 2015/16, according to available data. In 2018, private vehicles accounted for 96% of registered passenger vehicles, as reported by the Department of Transport Management. The transportation sector has significant adverse effects, particularly in terms of air pollution in urban areas and the global emission of greenhouse gases, with a significant impact on the local population, especially the poor in developing nations [12]. Sustainable urban mobility is built upon four pillars: social, environmental, economic, and institutional aspects, as highlighted by United Nation (UN) Habitat [13] .The increasing demand for public transport is raising concerns about overcrowding, as the capacity struggles to keep up. To fully understand the benefits that improved public transport can bring in terms of reduced crowding, it is crucial to identify meaningful measures of crowding that reflect the experiences of travellers. This study aims to quantify the load factor for peak and non-peak hours on different road sections and types of public vehicles.

Materials and methods

Study area

Kathmandu, the capital city of Nepal, is widely recognized as a major hub of air pollution in South Asia. Its geographical characteristics, with a bowl-shaped structure and an elevation of 1300m above sea level, surrounded by towering mountains, present a unique scenario for studying the impact of pollution trapped by topography and local weather patterns [14]. The once revered city of temples has now undergone a disturbing transformation into a city plagued by pollution. The pristine blue hills and clear skies that adorned the valley just a couple of decades ago have been replaced by a dull grey haze caused by the stagnant smog enveloping the area [15].

The selection of these road sections was based on high and medium traffic congestion levels, and the length of the road section was chosen to represent the average distance travelled by passengers during a trip (Fig. 1). To ensure a meaningful comparison of the air quality inside vehicles, samples were collected from three different routes with varying traffic conditions (Table 1).

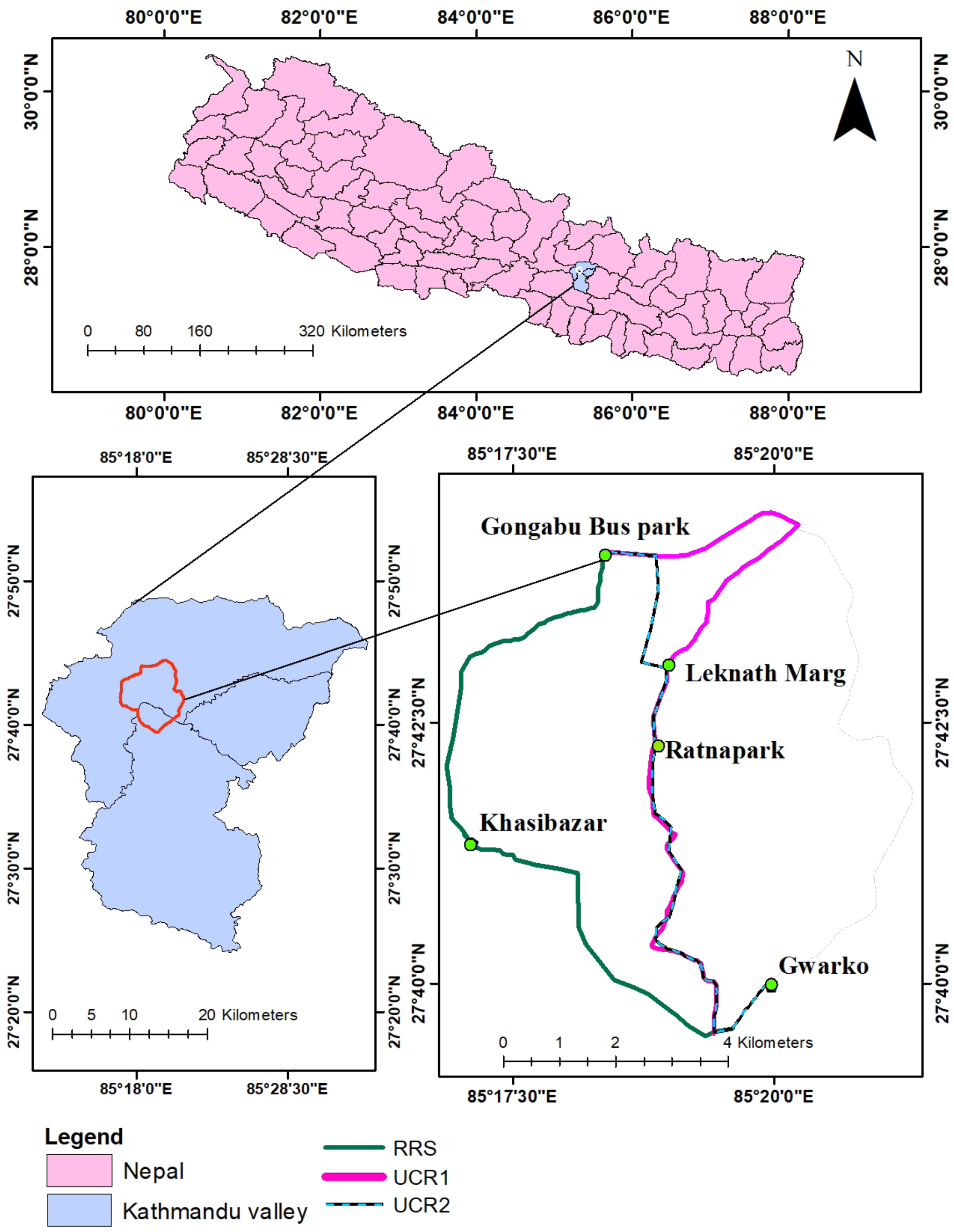


Fig. 1. Road section under study

Table 1. Details of sampling sections

Study Sections	Road location	Vehicle used	Length (km)
Ring road section (RRS)	Gwarko-Khasibazar-GongabuBus park	Mahanagar Yatayat	14.2
Urban commercial route 1 (UCR1)	Gwarko-Ratnapark-Chakrapath-Gongabu Bus park	Sajha Yatayat	15.2
Urban commercial route 2 (UCR2)	Gwarko-Ratnapark-Thamel Bus stop -Gongabu Bus park	Hiace	11.5

Urban commercial route 1 (UCR1)

The chosen route from Gwarko to Ratnapark via Chakra Path and Gongabu Bus Park covers a 15.2 km distance and is known for its heavy traffic, frequent congestion, and relatively low speeds. It divides the Ring road into two sections in Kathmandu city and is used by motorbikes, microbuses, buses, and private vehicles. This section is significant, hosting embassies, medical colleges, hospitals, and government institutions. In-vehicle air quality sampling was conducted on this route, specifically on Sajha Yatayat.

Urban commercial route 2 (UCR2)

The chosen 11.5 km route from Gwarko to Ratnapark, passing through Lekhnath Marg and Gongabu Bus Park, is known for its heavy traffic, frequent congestion, and slow traffic speeds. It divides the Ring road in Kathmandu City's center, primarily used by motorcycles, microbuses, buses, and personal vehicles. This area is significant due to the presence of embassies, governmental organizations, Thamel (a popular tourist destination), and restaurants. Air quality sampling was conducted on this route using Hiace cars.

Ring road section (RRS)

This specific route spans 14.2 km, running from Gwarko to Gongabu Bus Park. It features a moderate level of traffic density, and congestion tends to occur at key intersections during peak traffic hours. The roads, while relatively wide, are undergoing expansion work on the side sections, resulting in occasional airborne dust. Mahanagar Yatayat vehicles were used for air quality sampling on this route. Notably, the major entry points to the Kathmandu Central Business District (CBD) like Gwarko, Kalanki, and Gongabu are situated along the Ring road. Additionally, areas within the inner core, such as Lagankhel, Jawalakhel, Ratnapark, and Maharajgunj, further justify our choice of the Ring road as the primary focus of our study.

Data collection

Primary data collection method

The data was gathered using air quality measurements made on the ground. For the various road sections displayed in Table 1 along with the distance of each route and the kind of public transit being taken into consideration, primary data were gathered by field surveying using an IQ Air Visual pro N1 model air quality measurement system.

On-Site air quality sampling procedure

The gathering of primary data to determine the different public transportation trip characteristics within the Kathmandu Valley. Randomly selected samples were taken for public transportation, and the same vehicle is used to drive the entire trip. Three distinct types of vehicles were sampled three times on each segment during peak (8 AM to 10:30 AM and 4 PM to 6 PM) and non-peak (11 AM to 3 PM) hours on weekdays and weekends. The sampling was carried out from November 5 to December 20, 2022, over a 24-h period without rain. First, during rush hour, the vehicles were boarded at the pre-determined starting location, and the devices were fitted both indoors and outdoors of the vehicles [14] with an approximate sampling height of 1.8 m. Two devices were used on a single vehicle, one inside the vehicle and the other outside the vehicle (outside window), to record outdoor air quality parameters at intervals of 10 s through Air Visual Pro. These procedures were repeated during non-rush hour too in addition total sample size at each road section was 12 (Table 2). Since none of the transportation methods employed for this investigation had air conditioning, windows were left open and sampling equipment was placed close to the cabin seat on each trip to reduce bias [16]. Since smoking was forbidden in all forms of public transportation in this area, no one was caught breaking the law during the sampling period.

The I/O ratio is defined as follows:

$$I/O\ ratio = \frac{C_{in,i}}{C_{out,i}} \qquad (1)$$

Where, at time i, $C_{in,i}$ means indoor PM concentration and $C_{out,i}$ means outdoor PM concentration, with both being based on hourly data in this study.

For each mobile excursion, the average in- and out-vehicle PM_{10}, $PM_{2.5}$, and PM_1 concentrations were computed. Following this, an overall average in-vehicle air pollutant level for each road section was determined and compared to the 1-h National Nepal Indoor Air Quality Standard and Guideline [17] and the 8-h World Health Organization (WHO) Permissible Exposure Guidelines for $PM_{2.5}$, PM_{10}, PM_1 and CO_2.

Traffic speed

Each sample vehicle's time spent traveling the sample route was noted. Google Earth was used to determine the length of the route. Route length divided by time yielded the average traffic speed.

Load factor sampling procedure

To collect data on passenger load, we employed the quantitative count method where, we individually counted the number of passengers during each travel section. We determined the average number of passengers by considering the counts from the starting point to the endpoint of the sampling section [18]. Since, it was not practical to continuously count the passengers entering and exiting during sampling, we made slight modifications to the sampling procedure described in other studies [19]. We adopted the same sampling procedure for all sections and different types of public vehicles included in our study. To assess the passenger load, we calculated the load factor for subsections within the main road sections, as presented in Table 3. We counted the number of passengers at 10-min intervals, noting the start and end of each subsection. We then calculated the average number of passengers per trip.

Sampling was conducted during various hours of the day, considering peak and non-peak hours on both weekdays and weekends, to capture different passenger movements. The sample size and sampling sections are detailed in Table 3.

Table 2. Total number of sample size

Road Sections	Weekdays		Weekend		Sample size
	Peak	Non-peak	Peak	Non-peak	
Ring Road Section (RRS)	3	3	3	3	12
Urban Commercial Route 1 (UCR1)	3	3	3	3	12
Urban Commercial Route 2 (UCR2)	3	3	3	3	12

Table 3. Sampling sub-sections for load factor

Vehicle type	Road section	Sub-sections
Mahanagar	RRS (n=12)	Gwarko-Khasibazar
		Khasibazar-Gongabu Bus park
Sajha	UCR1 (n=12)	Gwarko-Lagankhel
		Lagankhel –Ratnapark
		Ratnapark -Gongabu Bus park
Hiace	UCR2 (n=12)	Gwarko-Lagankhel
		Lagankhel –Ratnapark
		Ratnapark -Gongabu Bus park

Table 4. LOS threshold for crowding

LOS	Load Factor (passenger/seat)	Standing Passenger Area (ft^2/passenger)	(m^2/passenger)	Comments
A	0.0-0.50	>10.8	>1.0	No passenger needs to sit next to another
B	0.51-0.75	8.2-10.8	0.76-1.0	Passengers can choose where to sit
C	0.76-1.0	5.5-8.1	0.51-0.75	All passengers can sit
D	1.01-1.25	3.9-5.4	0.36-0.50	Comfortable standee load for design
E	1.26-1.50	2.2-3.8	0.20-0.35	Maximum Schedule load
F	>1.50	<2.2	<0.20	Crush Load

The load factor analysis was extended to include the Ring road and urban commercial sections, following the methodology outlined [20] (refer to Table 4).In many conventional bus services worldwide, the number of standing passengers per square meter (m²) is a commonly used objective measure to assess crowding. This measure aligns with the crowding standard employed by Researchers [21] in the conventional bus industry. As per the most recent edition of the Transit Capacity and Quality of Service Manual (TCQSM) from 2003, a load factor of 1.0 indicates full occupancy, with every seat being occupied [22].

Secondary data collection method

The Department of Transport Management (DoTM) and various bus and micro-bus committees that operate on the Ring Road served as the primary sources of secondary data. This data encompassed details such as the composition of vehicles, public vehicle routes, and additional information regarding the types of vehicles.

To determine the length of the sample route, we utilized Google Earth, which provided accurate measurements for the chosen route.

Data analysis

For the statistical analysis and testing of the data SPSS version 25.0, RStudio 4.2.1, MS Excel, Origin lab 2023 tools are used. Descriptive statistics were calculated and analysed for pollutants concentration. Different test performed were Kruskal-Wallis Test ,Mann Whitney U Test.Shapiro-Wilk test was performed to check the normality of data before analysis. Further, Spearman correlation is performed to find the association between the pollutants and different parameters under study. To examine the significance of variance on in-vehicle concentrations of particulate matter across three sampling sites, the Kruskal-Wallis test was employed. In addition Mann-Whiteney test is employed to investigate the significance of variance in in-vehicle concentration of particulate matter between different hours namely peak and non-peak hours.

Quality control and quality assurance

For checking the accuracy of data collected from the field, device was collocated. Reference device for collocation was GRIMM EDM 180 monitor of ICIMOD. Two sensors used in data collection one of them was collocated with GRIMM EDM 180 monitor at Air Quality Monitoring Station (AQMS) ICIMOD for four days and one was collocated with Bluesky- TSI at roof of Central Department of Environmental Science, Tribhuvan University (CDES-TU). Regression equation for all devices were developed using MS Excel. PM data were corrected using the equations developed from simple linear regression. To validate the accuracy of the Air Visual Pro, reference PM values were obtained from the GRIMM EDM 180 sampler. Regression values were derived from a scatter plot comparing the reference PM values with those recorded by the Air Visual Pro. Outliers and blank values were removed using filter option.

Results and discussion

In-Vehicle air quality

Mean in-vehicle PM_{10} concentration ranged from 75 $\mu g/m^3$ to 550 $\mu g/m^3$, $PM_{2.5}$ concentration ranged from 25 $\mu g/m^3$ to 270 $\mu g/m^3$ while PM_1 concentration ranged from 10 $\mu g/m^3$ to 105 $\mu g/m^3$ among all samples (Table 5).Likewise higher concentration of all particulate matter during peak hours in comparison to non-peak hours for all road segments understudy (Table 6).Mean in-vehicle PM_1 concentration was found highest in UCR2 and lowest on UCR1 (Fig. 2) .The significant difference in $PM_{2.5}$ concentration on three route was found through Kruskal-Wallis test (Table. 7).

Table 5. Mean in-vehicle concentration of air pollutants for three routes (Mean ±S.D.)

Parameters	RRS (n=12)	UCR1 (n=12)	UCR2 (n=12)
PM_{10} (µg/m³)	270.00±62.63	240.22±76.04	237.26±70.86
$PM_{2.5}$ (µg/m³)	109.21±31.61	103.07±32.04	99.79±27.23
PM_1 (µg/m³)	53.04±18.25	33.53±9.58	66.91±18.00
CO_2 (ppm)	612.11±111.66	621.30±41.78	638.55±35.27

Table 6. Mean in-vehicle concentration of pollutants in three routes for different hours (Mean ±S.D.)

Parameters	RRS		UCR1		UCR2	
	Peak	Non-peak	Peak	Non-peak	Peak	Non-peak
PM_{10} (µg/m³)	311.50±57.14	206.09±68.12	286.59±76.62	193.86±75.47	271.08±81.90	203.44±59.82
$PM_{2.5}$(µg/m³)	140.02±39.64	78.41±23.58	135.11±38.80	71.02±25.28	128.68±32.95	70.90±21.51
PM_1 (µg/m³)	57.57 ±23.18	48.52 ±13.32	35.50 ±10.75	31.56 ±9.51	69.27 ±20.59	64.55 ±15.41
CO_2(ppm)	629.21±125.96	595.42±97.36	642.75±46.00	600.36±30.56	664.75±37.56	612.36±32.98

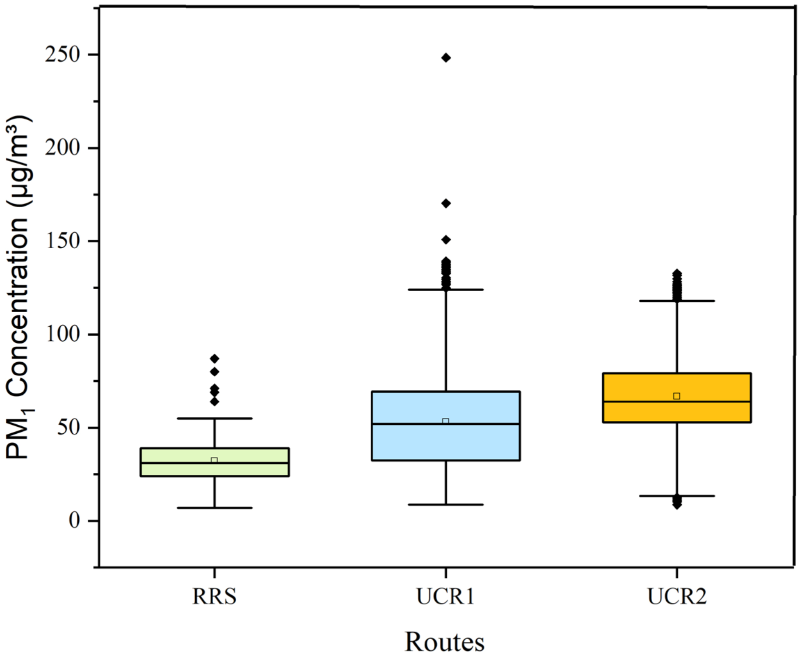
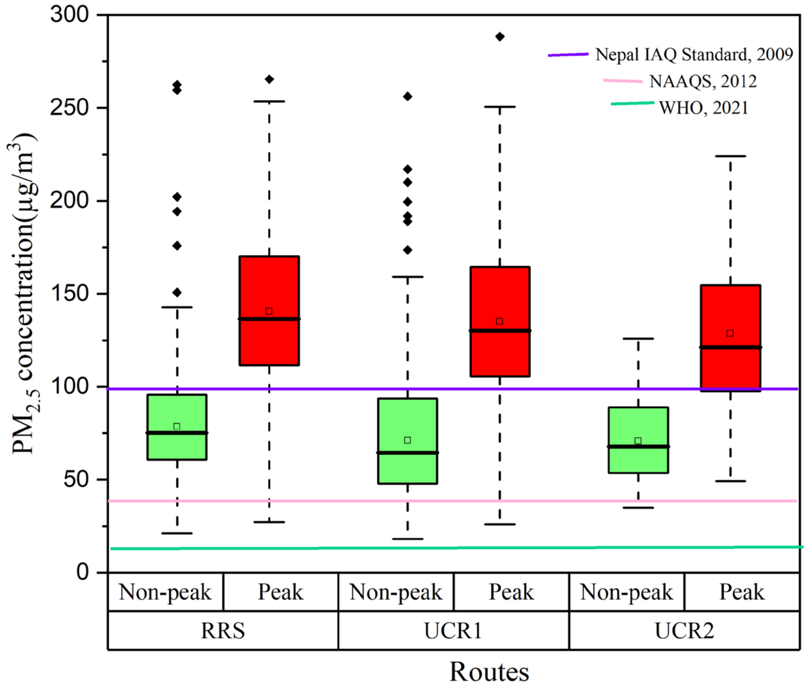


Fig. 2. Mean in- vehicle PM_1 concentration on different routes

Mean in-vehicle $PM_{2.5}$ concentration was found highest in RRS and lowest on UCR2. The significant difference in $PM_{2.5}$ concentration on three route was analyzed through Kruskal-Wallis test (Table 7). Mean in-vehicle $PM_{2.5}$ concentration on different hours was found highest in RRS and lowest on UCR2 (Fig. 3).

Mean in-vehicle PM_{10} concentration was found highest in Ring road section and lowest on UCR2 (Fig. 4). The significant difference in PM_{10} concentration on three route was analyzed through Kruskal-Wallis test (Table 7).



*Peak=8AM to 10:30 AM and 4 PM to 6 PM, Non-peak=11AM to 3 PM

*IAQ=Indoor Air Quality, NAAQS=National Ambient Air Quality Standard, WHO=World Health Organization

Fig. 3. Mean in-vehicle $PM_{2.5}$ variation on different hours for road sections

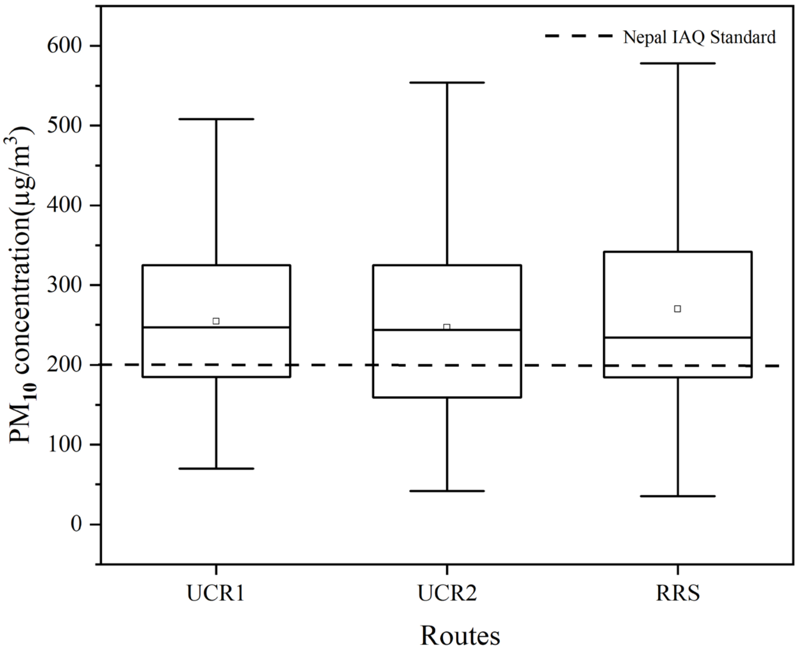


Fig. 4. Mean in-vehicle PM_{10} concentration on different routes

Table 7. Test statistics for Kruskal-Wallis test

Parameters	Kruskal-Wallis H	Significance Level
PM_1	13.35	<0.001
$PM_{2.5}$	32.18	<0.001
PM_{10}	36.16	<0.001

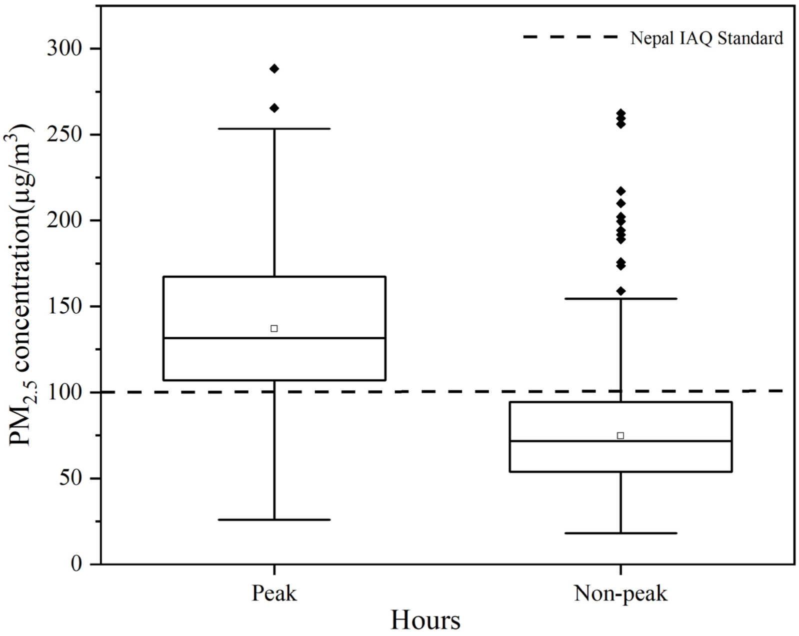


Fig. 5. Mean in-vehicle $PM_{2.5}$ concentration on different hours

A high traffic area's annual PM_{10} concentration was determined to be 261.4 µg/m^3 [23]. A significant difference in mean in-vehicle PM_1,$PM_{2.5}$ and PM_{10} concentration was analyzed between three routes (Kruskal Wallis test, $P<0.01$).There might be numerous factors contributing a difference in vehicle of three sections, one of the main reason might be the resuspension of dust and poor road quality, the road side deposition of loose sediments ,vehicular emissions. The Ring road section from Kalanki-Gongabu was poor with damaged pavement and loose sediments due to road side work progress causing exposure to particulate matter, and the urban core section from Chakra path to Gongabu was also not satisfactory which might have added significant difference in PM_{10} exposure to commuters. But less PM pollution found as compare to this similar study which was done over valley might be due to construction of road sections like on Ring road was running during sampling time [24]. Kathmandu Valley's urban challenges including congestion, inadequate mobility, inadequate transport service, and poor air quality [25]. Nepal's National Indoor Air Quality (IAQ) Standards and Implementation guideline [17] suggest the acceptable concentration of PM_{10} as 200 µg/m^3 for 1-hr average time. Around 75% of the exposure concentration exceeds the standard for PM_{10} on general scenario and almost all sampling route exceed the WHO Indoor Air Quality [26]. The previous study conducted on same month shows the continuous accumulation of PM_{10} in the ambient air during the wintertime [27]. So, seasonal variation could be one of the reason behind exceeding the Nepal's National Indoor Air Quality Standards and Implementation Guideline of this study.

Mean in-vehicle $PM_{2.5}$ concentration was found highest in peak hour than on non-peak hour (Fig. 5).

Table 8. Test statistics for Mann-Whitney U test

Mann-Whitney U	Wilcox W	Significance level
321	492	<0.001

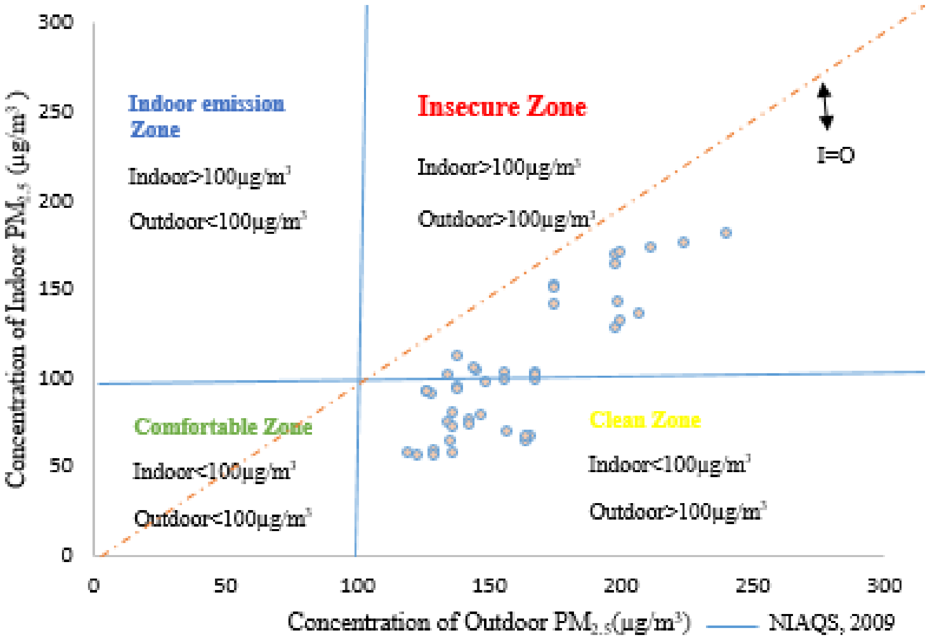


Fig. 6. Diagram of indoor $PM_{2.5}$ concentration by outdoor $PM_{2.5}$ concentration comparing to NIAQS

A significant difference is found in mean in-vehicle $PM_{2.5}$ concentration for peak and nonpeak hour (U-test, P<0.01) (Fig. 5).This could be the result of higher mobility of vehicle and other industrial activities during peak hours than on nonpeak hour. The significant difference in $PM_{2.5}$ concentration for peak and non-peak hour was found through Mann-Whitney U test (Table 8).

Comparing I/O ratio with national indoor air quality standard, 2009

In this study (Fig. 6) indoor and outdoor $PM_{2.5}$ were compared based on the indoor concentration maintenance standard of 100 µg/m³ according to National Indoor Air Quality Standard [17]. The x-axis and y-axis represent outdoor and indoor $PM_{2.5}$ concentrations, respectively.

From Fig. 6 around half of the sample lies on clean zone according to IAQ standard where indoor is<100µg/m³ and outdoor is>100µg/m³ while around half of the sample lies on insecure zone of exposure according to IAQ standard where indoor is> 100 µg/m³ and outdoor is>100 µg/m³.

Indoor and outdoor $PM_{2.5}$ were compared based on the indoor concentration maintenance standard of 100 µg/m³ according to National Indoor Air Quality Standard, 2009 [17]. IO ratio is<1 for $PM_{2.5}$ was for almost all sampling vehicles for all road sections which indicates the ambient environment as source of polluting in-vehicular air quality [28] (Fig. 6). Different factors influence the contribution of outdoor pollution on indoor environments are constituted by the type of ambient ventilation (i.e., natural or mechanical), distance to the sources, and meteorological conditions [29, 30].

This might be due to the influence of meterological condition as indicated in a literature, where it depicted that temperature, humidity and solar irradiation play a vital role in the variation of the IO ratio. On the other hand, both pressure and wind speed have relatively little effect on the IO ratio [31]. IO ratio close or equal to one which indicates almost equal concentration of fine particulates on both in-vehicle (cabin) and ambient atmosphere due to high ventilation effect. If a window is open the ratio IO is close to 1 (I=O) for all particle sizes [32]. In case of I>O, there is higher the value of indoor pollutants comparing to ambient/outdoor which indicates the self-polluting source for cabin environment such as engine fume leakage contamination [28] or could be lack of detection by out-vehicle sampling during mobile testing.

Comparison of ratio between pollutants

Table 9 summarizes the dominance of pollutants for both ambient and in-vehicle condition from ratios between fine and coarse particle. Generally , dominance of coarse particle is higher than fine particle for both ambient and in-vehicle environment. Higher fraction of finer particle is for in-vehicle condition in comparison to ambient environment.

Comparison of ratio status of PM_{10} and $PM_{2.5}$ for in-vehicle air quality as well as ambient air quality shows strong interdependence of $PM_{2.5}$ and PM_{10} with dominance of coarser particle (Table 9), implying that it can provide extra information about the aerosol pollutants . Previous study also implies at the Ratnapark site in Kathmandu where, resuspended dust contributed substantially to PM, accounting for an average of 51% of coarse particle mass [33]. The finding from the study complies by researchers [34] during post–monsoon season the ratios of $PM_{2.5}$ / PM_{10} was ranged between 0.17–0.72. Correlations between PM_{10} and $PM_{2.5}$ (r=0.83, P<0.01) (Table 10) shows the higher association of particles and indicates common source of emission supported by the study. Literature suggests that the major sources of PM_{10} and $PM_{2.5}$ are common which could be re-suspension dust from road. Such correlations have been reported by previous studies on traffic air pollution [35]. Generally, a lower $PM_{2.5}$/PM_{10} ratio indicates coarse particles dominant, which is more attributed to natural sources [36-38] which was found in our study .These results are satisfactory because road dust contributes to coarse particles like PM_{10} as well as fine particles like $PM_{2.5}$ while vehicular emission contributes a fraction of finer particles like $PM_{2.5}$ too [24].

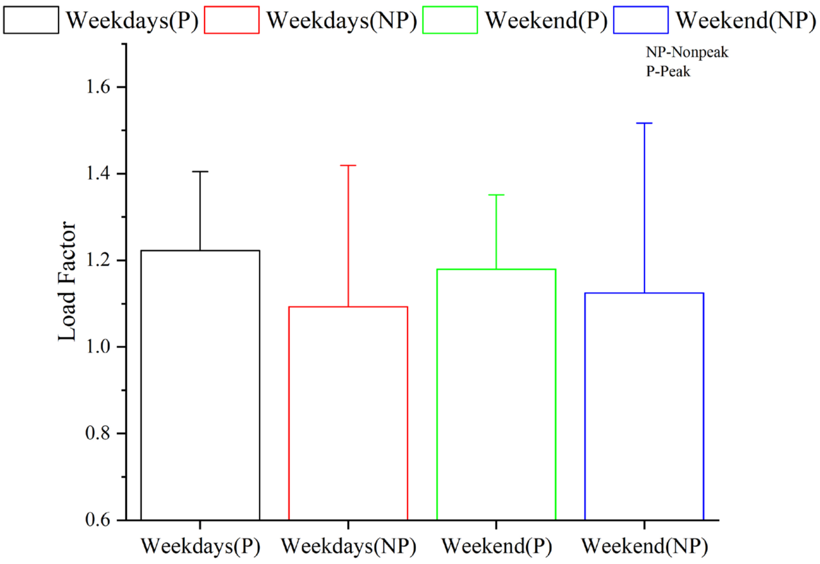
Table 9. Comparison of ratio between pollutants

Ratio	$PM_{2.5}/PM_{10}$
Ambient	0.40
In-vehicle	0.45

Table 10. Correlation between particulate matter and load factor

	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	Load factor
PM_{10} (µg/m³)	1.000		
$PM_{2.5}$ (µg/m³)	0.832**	1.000	
Load factor	0.596**	0.628**	1.000

** Correlation is significant at the 0.01 level



*NP=Non-peak, P=Peak

Fig. 7. Load factor across different sections in different time

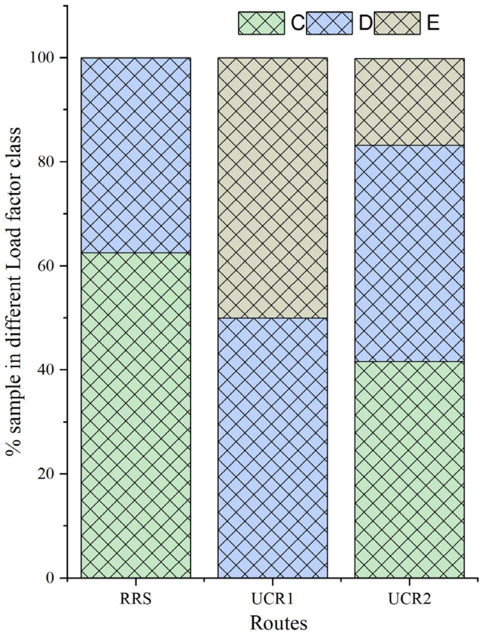


Fig. 8. Fractional representation of Load factor for different sections

Load factor

Load factor and level of safety (LOS) for various types of vehicles marked by day and period

Load factor is found highest for the peak hours and lowest for nonpeak hours for both weekdays and weekends (Fig. 7). Comparing between weekdays and weekends load factor for nonpeak hour is highest for weekend. Along with the increase on load factor, LOS is also decreasing from C to E on respective road sections (Fig. 8). On RRS (Mahanagar Yatayat) load factor for both peak and nonpeak hour were comparatively less than on other section .The load factor for weekend was higher on nonpeak hour than on weekday's nonpeak hour. Among three vehicles the maximum load factor was observed on UCR1 for overall scenario minimum LOS "D" and maximum LOS "E".

The load factor was calculated and interpreted according to a study by researchers [39]. The respective LOS for peak and non-peak hour of weekdays and weekend signifies during weekdays for RRS LOS is "C" which indicates all passengers can sit for both peak and non-peak hour. For weekends LOS peak is "D" which indicates comfortable standee load for design and for non-peak LOS is "C", which implies all passengers can sit (Fig. 8). A load factor of 1.0 indicates that all seats are occupied. The load factor is below or equals to one for the road section for Gwarko-Khasibazar-Gongabu (RRS), which indicates the section is comparatively satisfying passenger demand for public transportation with respect to Sajha and Hiace road section. Mahanagar Yatayat services are 86.6% efficient whereas microbuses are 56.5% efficient [19].

For UCR1 (Gwarko-Lagankhel-Ratnapark-Gongabu) load factor is almost greater than one in case of weekdays and weekend for both peak and non-peak hour. This section includes LOS "D" and LOS "E", which indicates comfortable standee load and maximum schedule load with low standing passenger area 3.9-5.4 (m^2/passenger), and 2.2-3.8 (m^2/passenger) respectively. This section shows higher passenger demand for public vehicle comparing to RRS which might decreases the satisfaction of passenger due to crowding factor, supported by a study [40], which suggest 65% passengers dissatisfied with limited availability of public vehicles at evening and night-time. However, the majority of passengers are dissatisfied with the accessibility, comfort, cleanliness, and safety of public transportation. Only the transportation fare provides satisfaction to passengers. Another survey conducted by the World Bank on 2013 ranked the concerns of commuters as follows: overcrowding (75%), personal insecurity (26%) and reckless driving and fear of accidents (17%).The higher load factor for both peak and non- peak hour may be due to one of the core road section connecting diagonally to Ring road which includes Medical college and hospital, army office, restaurants, (Lagankhel, Ratnapark, Thamel, Lainchaur) core city area for tourist and other peoples ,embassies, Department of Passport, Department of mine and geology and other governmental offices as major entity. The higher mobility of people is due to the services provider on this section.

On a general scenario 68.75% of the sample exceed the capacity of vehicle i.e. Load factor>1. During weekends 82% of sample exceed the load factor greater than one. Beside other technological aspects air pollutant emissions are related physical parameters, such as slope of the infrastructure, vehicle load [40]. Higher load factor was for peak hour than non-peak hours from our study complies with a study which showed that vehicle occupancy differed by geographic area, highway class, and time of day [41]. Hence higher load indicates peak hour and contributes higher vehicular emission including particulate matter. Automobile exhaust is the main cause of $PM_{2.5}$ pollution [42].

Correlation between particulate matter and load factor

There is strong correlation between load factor and $PM_{2.5}$, r=0.62, P<0.01 as being one of the major particulates emitted by vehicular emission, followed by correlation between load factor and PM_{10} r=0.596, P<0.01. The high positive correlation between $PM_{2.5}$ and PM_{10} r=0.83, P<0.01 was in in-vehicle air quality (Table 10).

Quality control and quality assurance

Sensor validation

The Air Visual Pro is an affordable sensor that records data at 10-s intervals. The raw data from an Air Visual Pro was collected. These raw data points were then aggregated to create 1-min averages. For a comprehensive analysis, three days' worth of data were collected from an Air Visual Pro set up at AQMS in Khumaltar. Using a Python script within Visual Studio Code, 1-min average data was synthesized from the 10-s data recorded by the device, spanning from June 5 at 17:00 P.M. to June 9 at 10:00 A.M.

To validate the accuracy of the Air Visual Pro, reference PM values were obtained from the GRIMM EDM 180 analyser. Regression values were derived from a scatter plot comparing the reference PM values with those recorded by the Air Visual Pro as shown in Fig. 9. Any outliers and blank values were meticulously removed through the use of a filter option.

To enhance data accuracy, a PM correction equation was developed based on the results of the linear regression analysis. This equation was then applied to the Air Visual Pro data, resulting in corrected PM values. A line plot was constructed, comparing the Reference PM values both before and after the correction process for three Air Visual Pro devices. This evaluation aimed to assess the improvements in data accuracy brought about by the correction method.

The PM_1, $PM_{2.5}$ and PM_{10} sensor signals compared to the reference signals observed during the calibration process are shown in Fig. 9.

Conclusion

Mean In-vehicle PM_{10} and $PM_{2.5}$ concentration were highest in Ring road section and lowest in Urban commercial route (UCR1).Particulate matter both PM_{10} and $PM_{2.5}$ frequently crossed the standards by Nepal government for IAQ and almost all sampling route exceed the WHO Indoor Air Quality Guideline, 2021.One of the main reason might be the resuspension of dust and poor road quality, the road side deposition of loose sediments, and vehicular emissions. The Ring road section from Kalanki-Gongabu was poor with damaged pavement and loose sediments due to road side work progress causing high exposure to particulate matter, and the urban core section from Chakra path to Gongabu was also worst which might have increased exposure to commuters. The higher vehicular congestion in urban commercial section is also another cause of high emission and higher exposure to commuters during peak hours than nonpeak hours as, mean in-vehicle concentration of PM_{10}, $PM_{2.5}$, PM_1 and CO_2 were highest during peak hour and lowest during nonpeak hour in all sampling vehicles. Abatement of road and construction dust is needed to reduce PM_{10} within WHO guideline value. Comparison of ratio status of PM_{10} and $PM_{2.5}$ for in-vehicle air quality as well as ambient air quality shows higher fraction of fine particle on in-vehicle comparing to ambient which shows possibilities of severe health impacts with fine particulate matter. so, concerned authority should focus on good air purifier on public vehicle for reducing the impact. Strong interdependence of $PM_{2.5}$ and PM_{10}, indicates that the major sources of PM_{10} and $PM_{2.5}$ are common which could be re-suspension dust from road and vehicular emission. For $PM_{2.5}$ the IO ratio is less than one for almost all sampling vehicles for all road sections which indicates the ambient environment as source of polluting in-vehicular air quality.

Generally during peak hour around 80% of the sample exceed the capacity of vehicle i.e. Load factor>1.The higher load factor for both peak and non-peak hour for Urban Commercial Section may be due to one of the core road section connecting diagonally to ring road which includes Medical college and hospital, army office, restaurants, (Lagankhel, Ratnapark, Thamel, Lainchaur) core city area for tourist and other peoples ,embassy, Department of passport ,Department of Mine and Geology and other governmental offices. The higher mobility of people is due to the services provider on this section. But for Ring road section load factor is comparatively less. The strong correlation between load factor and $PM_{2.5}$ might be due to one of the major particulates emitted by vehicular emission, followed by load factor and PM_{10}, load factor, which that during peak hours commuters are at high risk of exposure to particulate matter.

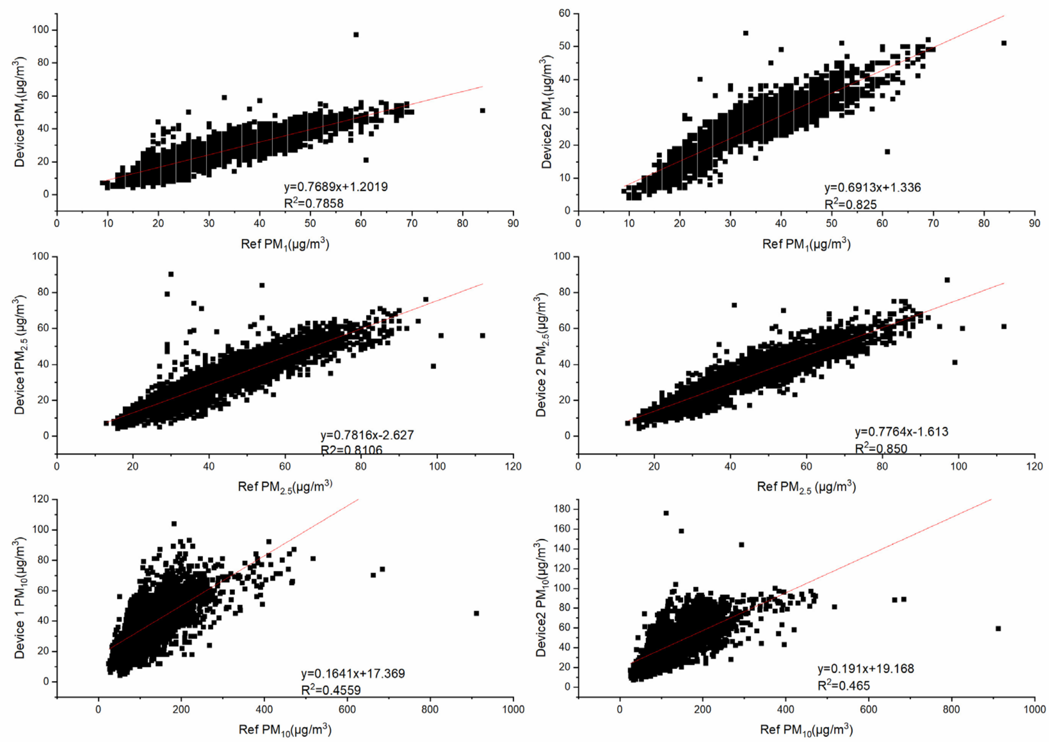


Fig. 9. Scatter-plots of sampled signals vs. reference signals observed during sensors calibrations

Financial supports

I am thankful to the Resources Himalaya Foundation (RHF) for providing me with a grant to perform this research project, grant number 12-RHF-2079.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to thank the Central Department of Environment Science, Tribhuvan University, Kritipur. Nepal for giving us an oppotunity to conduct research by providing necessary equipments to carry out the research.

Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely ob-served by the authors.

References

1. Mayer H. Mayer: Cities. Atmos Environ. 1999;33(24):4029–37.

2. Tartakovsky L, Baibikov V, Czerwinski J, Gutman M, Kasper M, Popescu D, et al. In-vehicle particle air pollution and its mitigation. Atmos Environ. 2013;64:320–8.

3. Saud B, Paudel G. The Threat of Ambient Air Pollution in Kathmandu, Nepal. J Environ Public Health. 2018 Jul 10;2018.

4. Das B, Bhave P V., Puppala SP, Byanju RM. A Global Perspective of Vehicular Emission Control Policy and Practices: an Interface With Kathmandu Valley Case, Nepal. J Inst Sci Technol. 2018;23(1):76-80.

5. Kloog I, Chudnovsky AA, Just AC, Nordio F, Koutrakis P, Coull BA, et al. A new hybrid spatio-temporal model for estimating daily multi-year $PM_{2.5}$ concentrations across northeastern USA using high resolution aerosol optical depth data. Atmos Environ. 2014;95:581-90.

6. Rodopoulou S, Samoli E, Chalbot M-CG, Kavouras IG. Air pollution and cardiovascular and respiratory emergency visits in Central Arkansas: A time-series analysis. Sci Total Environ. 2015;536:872-9.

7. Aithal SS, Sachdeva I, Kurmi OP. Air quality and respiratory health in children. Breathe. 2023;19(2).

8. Hildebrandt ML, Pokhrel S. Climate and air quality: a case study of PM_{10} pollution in Kathmandu, Nepal. InPapers and proceedings of applied geography conferences 2002 (Vol. 25, pp. 27-35). [np]; 1998. Available from: https://www.researchgate.net/publication/266339577

9. Kathmandu N. Central bureau of statistics. Population (in million). 2014 Aug;33:34-0.

10. Clean Air Network Nepal. Urban Mobility in Kathmandu Status and Trend. 2013. Available from: https://www.cen.org.np/uploads/doc/urban-mobility-ktm-maya-factsheet-1-60b9f912e0e7c.pdf

11. JICA S. Data Collection Survey on Traffic Improvement in Kathmandu Valley. In2nd Workshop. [Presentation Slides] 2012.

12. Teri V, Libor C, Jiri N, Helena P, Blanka K, Irina N, et al. An investigation of local and regional sources of fine particulate matter in Ostrava, the Czech Republic. Atmos Pollut Res. 2015;6(3):454–63.

13. Habitat UN. State of the world’s cities 2012/2013: Prosperity of cities. Routledge; 2013 Oct 23.

14. Mahapatra PS, Puppala SP, Adhikary B, Shrestha KL, Dawadi DP, Paudel SP, et al. Air quality trends of the Kathmandu Valley: A satellite, observation and modeling perspective. Atmospheric environment. 2019 Mar 15;201:334-47.

15. Pandey S. Poor air quality in Kathmandu: Causes, consequences and solutions explained. 2023; Available from: https://english.onlinekhabar.com/poor-air-quality-in-kathmandu-explain.html

16. Jiao W, Frey H. Method for measuring the ratio of in-vehicle to near-vehicle exposure concentrations of airborne fine particles. Transp Res Rec. 2013;(2341):34–42.

17. MoEST. National indoor air quality standards and implementation guideline. 2009;

18. Mulligan AM, Nicholson A. Uncertainty in traffic flow estimation using the moving-observer method. InIPENZ Transportation Group Conference Papers 2002.

19. Bhattarai B. Study on efficiency and satisfaction level of public transportation within Kathmandu inner ring road. Pulchowk Campus; 2017.

20. Li Z, Hensher DA. Crowding in public transport: A review of objective and subjective measures. J Public Transp. 2013;16(2):107–34.

21. Li Z, Hensher DA. Performance contributors of bus rapid transit systems within the ITDP BRT standard: An ordered choice approach. 2019.

22. Levinson H, Zimmerman S, Clinger J, Rutherford S, Smith RL, Cracknell J, et al. Bus rapid transit. Transit Coop Res Progr Rep. 2003;90.

23. Majumder AK, Islam KMN, Bajracharya RM, Carter WS. Assessment of occupational and ambient air quality of traffic police personnel of the Kathmandu valley, Nepal; in view of atmospheric particulate matter concentrations (PM_{10}). Atmos Pollut Res [Internet]. 2012;3(1):132–42. Available from: http://dx.doi.org/10.5094/APR.2012.013

24. Dhital NB, Hung WT, Byanju RM. Air pollution inside public transport vehicles of Kathmandu Valley. Nepal J Environ Sci. 2014;2:35–41.

25. Malla S. Assessment of mobility and its impact on energy use and air pollution in Nepal. Energy. 2014;69:485–96.

26. Organization WH. WHO air quality guidelines global update 2005: Report on a Working Group Meeting, Bonn, Germany, 18–20 October 2005. World Health Organization. Regional Office for Europe; 2005.

27. Aryal RK, Lee BK, Karki R, Gurung A, Kandasamy J, Pathak BK, et al. Seasonal PM_{10} dynamics in Kathmandu Valley. Atmos Environ [Internet]. 2008;42(37):8623–33. Available from: http://dx.doi.org/10.1016/j.atmosenv.2008.08.016

28. Alameddine I, Abi Esber L, Bou Zeid E, Hatzopoulou M, El-Fadel M. Operational and environmental determinants of in-vehicle CO and $PM_{2.5}$ exposure. Sci Total Environ [Internet]. 2016;551:42–50. Available from: http://dx.doi.org/10.1016/j.scitotenv.2016.01.030

29. Nazaroff WW. Indoor Partical Dynamics. Indoor Air [Internet]. 2004;14(7):175–83. Available from: https://escholarship.org/uc/item/7sq4x34d#author

30. Jones NC, Thornton CA, Mark D, Harrison RM. Indoor/outdoor relationships of particulate matter in domestic homes with roadside, urban and rural locations. Atmos Environ. 2000;34(16):2603-12.

31. Chan MY. Commuters' exposure to carbon monoxide and carbon dioxide in air-conditioned buses in Hong Kong. Indoor Built Environ. 2005;14(5):397-403.

32. Zhu Y, Hinds WC, Krudysz M, Kuhn T, Froines J, Sioutas C. Penetration of freeway ultrafine particles into indoor environments. J Aerosol Sci. 2005;36(3):303-22.

33. Islam MR, Li T, Mahata K, Khanal N, Werden B, Giordano MR, et al. Wintertime Air Quality across the Kathmandu Valley, Nepal: Concentration, Composition, and Sources of Fine and Coarse Particulate Matter. ACS earth Sp Chem. 2022;6(12):2955-71.

34. Abi-Esber L, El-Fadel M. Indoor to outdoor air quality associations with self-pollution implications inside passenger car cabins. Atmos Environ. 2013;81:450-63.

35. Bathmanabhan S, Saragur Madanayak SN. Analysis and interpretation of particulate matter - PM_{10}, $PM_{2.5}$ and PM_1 emissions from the heterogeneous traffic near an urban roadway. Atmos Pollut Res [Internet]. 2010;1(3):184–94. Available from: http://dx.doi.org/10.5094/APR.2010.024

36. Tian P, Zhang L, Ma J, Tang K, Xu L, Wang Y, et al. Radiative absorption enhancement of dust mixed with anthropogenic pollution over East Asia. Atmos Chem Phys. 2018;18(11):7815-25.

37. Wang YQ, Zhang XY, Sun JY, Zhang XC, Che HZ, Li Y. Spatial and temporal variations of the concentrations of PM_{10}, $PM_{2.5}$ and PM_1 in China. Atmos Chem Phys. 2015;15(23):13585–98.

38. Zhou X, Cao Z, Ma Y, Wang L, Wu R, Wang W. Concentrations, correlations and chemical species of $PM_{2.5}/PM_{10}$ based on published data in China: potential implications for the revised particulate standard. Chemosphere. 2016;144:518–26.

39. Li Z, Hensher DA. Crowding in public transport: a review of objective and subjective measures. J Public Transp. 2013;16(2):107–34.

40. Manandhar RB. Passengers' Satisfaction towards Service Quality with Public Transportation in Kathmandu Valley. Int Res J MMC. 2023;4(1):1-8.

41. Gan A, Jung R, Liu K, Li X, Sandoval D. Vehicle occupancy data collection methods. 2005.

42. Qin D-S, Gao C-Y. Control measures for automobile exhaust emissions in $PM_{2.5}$ governance. Discret Dyn Nat Soc. 2022;2022.