In-door Air Quality of Toll Workers in Accra, Ghana*

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Abstract

Toll attendants are occupationally uncovered to automobile engine exhaust, a complex mixture of various chemical substances, and in city air, this aggregate varies with the sort of car pushed (e.g., fuel, light-duty, heavy-obligation), in addition to with exhaust remedy technologies, gasoline formulations, engine working conditions (e.g., gas/air ratio, idle, acceleration, deceleration, load, velocity). The study aimed to investigate the Indoor Air Quality of highway Toll Attendants at Road-Toll Plazas in the Greater Accra Region of Ghana and assessed the risk of human exposure to specific air pollutants at the Toll Plazas. Aeroqual 500 with its interchangeable sensors was deployed for non-stop subject monitoring of particulate matter and gaseous emissions for three days every on the Accra, Kasoa, and Pobiman Toll Plazas. Common concentrations of particulate be counted and nitrogen dioxide had been discovered to be better than the Ghana standard and WHO guiding principle restriction. Concentrations for SO_2, CO, and TVOC remained within Ghana general and WHO guideline restrict. The Hazard Quotient (HQ) of the respective pollutants characterised over an entire life publicity situation become low (<1 for each pollutant) which indicates that the concentrations of the specific pollutants at the Toll Plazas may not constitute an adverse environmental health risk. But the Hazard Index (HI) which is an aggregate of the HQs from the individual pollutants, was estimated to be higher (HI>1.0 =>dangerous). Toll attendants have been exceptionally exposed to particulate depend and nitrogen dioxide which is dangerous.

Keywords: PM, TVOC, Toll Plaza, Hazard Index, Hazard Quotient

1 Introduction

Toll plazas serve as vital transit factors and gateways to city areas, facilitating the motion of vehicles and people (Safo-Adu et al., 2014). But, heavy site visitors' congestion and idling cars at toll plazas can extensively impact air excellent, main to increased tiers of pollution (Sehgal et al., 2015). In Ghana, where toll plazas play an important role in transportation infrastructure, it's far essential to evaluate and display the air pleasant in and around these places. This newsletter explores the ranges of Particulate Matter (PM), Carbon Monoxide (CO), volatile Organic compounds (VOCs), Nitrogen Dioxide (NO_2), and Sulfur Dioxide (SO_2) at toll plazas in Ghana, dropping mild on the potential implications for public health and the surroundings.

Particulate Matter (PM) refers to tiny debris suspended inside the air, together with dust, smoke, and different pollutants. Research have indicated that toll plazas experience accelerated PM degrees because of car emissions and avenue dust (Lai et al., 2004). These particles, specifically those within the high-quality particulate count number range (PM2.5 and PM10), can penetrate deep into the lungs and have unfavourable health consequences, such as breathing troubles and cardiovascular diseases (WHO, 2005). Carbon Monoxide (CO) is a colourless and odourless gas produced more often than not through the incomplete combustion of fossil fuels. Toll plazas often witness a high awareness of CO due to car emissions all through congestion and idling (Sehgal et al., 2015). Prolonged publicity to CO can cause headaches, dizziness, and, in intense instances, cardiovascular headaches. Tracking CO levels is vital to make sure the safety and well-being of toll plaza employees and commuters (WHO, 2005).

General volatile organic Compounds (TVOCs) are emitted from diverse sources, inclusive of automobile exhaust, gasoline evaporation, and business activities. Toll plazas may be hotspots for TVOC emissions due to automobile idling and the presence of fueling stations (Zhang, 2010). TVOCs contribute to the formation of ground-degree ozone and may have each quick-time period and lengthy-term health outcomes, which includes eye and respiratory irritations, or even ability carcinogenicity. Understanding and handling TVOC ranges are crucial for preserving air high-quality standards (WHO, 2005).

Nitrogen Dioxide (NO_2) is a damaging gas produced by way of the combustion of fossil fuels, especially from motors. Toll plazas with heavy traffic frequently experience extended NO_2 stages. Prolonged publicity to NO_2 can lead to respiratory troubles, accelerated chance of respiration infections, and aggravation of allergies signs and symptoms (Ali et al., 2017). Tracking NO_2 degrees provides insights into the effectiveness of site visitors management and emission manipulate measures (WHO, 2005).

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Surely all fossil fuels incorporate sulfur atoms (Zhang, 2010). Some of the sulfur in fuels is in the long run oxidized to Sulphur Dioxide (SO_2) and Sulphur Trioxide (SO_3). Natural sulphur is gift in the form of sulphides, mercaptanes, bisulphides, thiophenes, thiopyrones, and so forth. These organic compounds are also located in crude oils and gases (Zhang, 2010). Sulphur Dioxide is related to breathing troubles, especially in people with pre-existing situations together with allergies or persistent bronchitis. Tracking SO_2 degrees can assist identify ability sources and manual pollutants manage efforts (WHO, 2005).

Assessing the stages of PM, CO, TVOCs, NO_2, and SO_2 at toll plazas in Ghana is important for knowledge the impact of vehicle emissions on air fine. By way of monitoring and addressing those pollution, measures may be implemented to mitigate fitness risks and promote sustainable transportation practices. Endured studies and centered interventions will be essential to enhance air high-quality at toll plazas and safeguarding the well-being of both toll plaza employees and the public.

2 Resources and Methods Used

2.1 Study Location and Sites Selection

The study was performed in three Toll Plazas in Accra, the capital town of Ghana. Accra the capital city is registered to be the various fastest-growing towns in Sub-Sahara Africa (Sandow, 2016). The area is known to be the most urbanized place in Ghana with 87.4 percentage of its total residents living in city centers. It has a population of 5,455,692 in 2021 accounting for 17.7 percentage of Ghana's overall population (GSS, 2021). The region has 4 national highways – N1, N2, N4 and N6. The N1 enters the area in Ada to the east and runs west, intersecting the N2 at Tema. It continues and passes through Kokrobite and exits the area at Weija wherein it maintains through the imperative area. The N2 crosses the Eastern Regional border into Asikuma and runs north entering the Upper East Region. The N4 heads north from the Tetteh Quarshie Interchange, while the N6 originates from Achimota.

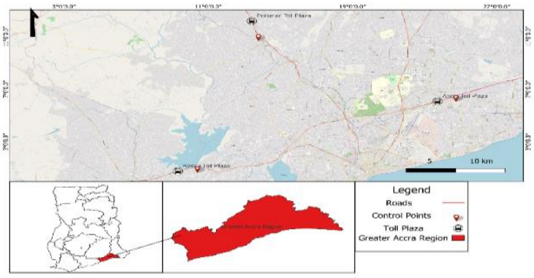

Fig. 1 Geographical Map of the Sampling Location in the Region

The three toll plazas, two positioned on N1 and one on the N6 had been selected (Fig. 1). The two at the N1 are positioned on the Tetteh Quarshie - Tema motorway (Accra Toll Plaza) and the alternative at Weija-Kasoa (Kasoa Toll Plaza). The alternative at the N6 is positioned at Pobiman (Pobiman Toll Plaza). The choice of these three plazas changed into primarily based on presumed worst-case publicity situations, mainly in the course of the rush hours of the day (morning and night). These toll plazas have ordinary congestion particularly, congestion initiated via excessive site visitors' densities in the course of the weekday top rush hour segment.

2.2 Sample Collection

Aeroqual portable Air quality display 500 (A-S500) [Aeroqual Limited, Auckland, New Zealand] became used to decide the concentration of particulate matter (2.5 and 10), Carbon dioxide, Nitrogen dioxide, Sulphur dioxide and Total Volatile Organic Compounds. The A-500 instrument includes a monitor base and interchangeable sensor heads.

The tracking was conducted inside the toll cabins wherein these employees sit down constantly for lengthy running hours at some stage in working time. The tracking become achieved for twenty-four hours for all parameters to determine their awareness. One cabin at every toll plaza with the best glide of vehicular actions become selected for the take a look at. Particulate 2.5 and 10 have been accrued the usage of Laser Particle Counter (LPC) sensor (Table 1). The Particle Profiler gives continuous and simultaneous dimension of PM10 and PM2.5. The Profiler incorporates an optical particle counter that converts counts to a mass fraction via a proprietary set of rules saved inside the machine firmware.

Measurements are logged and mentioned in real-time. The Profiler is configured to show and log particle mass. Carbon monoxide, Nitrogen dioxide and Sulphur dioxide were determined the use of fuel touchy Electrochemical (GSE) sensors (Table 1). The GSE sensors generate nano-amp currents proportional to the gasoline concentration which makes use of low- noise electronics to capture those indicators. General unstable natural Compounds had been determined the usage of Photoionization Detector (PID) sensor (Table 1). The PID sensor makes use of a krypton-crammed UV lamp to ionize TVOC gas molecules and generate a modern that is proportional to the TVOC awareness.

Table 1 Specifications for Aeroqual ambient sensors

Pollutants	Sensor type	Sensor range	Detection limit (mg/m^3)
$PM_{2.5}$ PM_{10}	LPC	0.001-1.000 mg/m^3	**0.001**
CO	GSE	0-100 ppm	**0.2ppm**
NO_2	GSE	0-1ppm	**0.005ppm**
SO_2	GSE	0-10ppm	**0.04ppm**
TVOC	PID	0-20ppm	**0.01ppm**

LPC [laser particle counter]; GSE [gas sensitive electrochemical]; PID [photo ionization detector]

2.3 Risk Characterization

Health risks had been calculated with the aid of concerning the anticipated publicity to the relevant concentration-reaction. The awareness reaction members of the family were assumed to hold for visitors-associated air pollution as shown by means of PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, and TVOC, and for each congestion and congestion-loose conditions which may be justified if the pollutant aggregate related to those conditions are related. But inhalation risk checks may additionally require that an adjusted air concentration be used to represent continuous publicity. For non-carcinogens, the air concentration is adjusted based totally on the time over which exposure occurs (i.e., the exposure period) and for carcinogens, the concentration is averaged over the life of the uncovered man or woman (regularly assumed to be 70 years) (US EPA 2008). The adjusted air attention is described as follows.

$$HQ = \frac{\text{Concentration intake (CI)}}{\text{Reference dose (RfD)}} \quad (1)$$

$$CI = \frac{\text{Conc. x CR x EF x ED x C}}{\text{BW x AT}} \quad (2)$$

Where conc is the concentration of pollutant, CR is the contact rate, EF is the exposure frequency, ED is the exposure duration, BW is the body weight, AT is the average time (period over which exposure is average), CF is the conversion factor.

$$HI = HQ_{PM10} + HQ_{PM2.5} + HQ_{NO2} + HQ_{SO2} + HQ_{CO} + HQ_{TVOC} \quad (3)$$

3 Results and Discussion

3.1 Particulate Matter ($PM_{2.5}$ and PM_{10})

Table 2 to 4 summarizes the results of the air fine performed on the three toll plazas within the area. As defined in Tables 2 to 4, the best 24-hour average attention of PM_{10} become discovered in Kasoa Toll Plaza (138.3 µg/m3), observed by using Pobiman Toll Plaza (128.7 µg/m3) and Accra Toll Plaza (67.0 µg/m3). The average concentrations of PM_{10} at Kasoa Toll Plaza and Pobiman Toll Plaza had been generally higher than the PM_{10} 24-hrs threshold restrict of 70 µg/m3 (Ghana standard 1236: 2019). However, the common concentration of PM_{10} at Accra Toll Plaza, Kasoa Toll Plaza, and Pobiman Toll Plaza turned into all higher than WHO permissible restriction (50 µg/m3). The variation within the concentration of PM_{10} on the three Toll Plazas changed into now not statistically considerable (p=0.09).

Also, the 24 hours average awareness of $PM_{2.5}$ observed a similar pattern of the PM_{10} at the Toll Plazas (table 2 to 4). The best average attention of $PM_{2.5}$ become located at Kasoa Toll Plaza (47.3 µg/m3), observed by using Pobiman Toll Plaza (47.0 µg/m3) and Accra Toll Plaza (31.7 µg/m3). The average concentrations of $PM_{2.5}$ at Accra Toll Plaza, Kasoa Toll Plaza, and Pobiman Toll Plaza have been normally higher than the $PM_{2.5}$ 24-hrs threshold restrict of 35.0 µg/m3 (Ghana fashionable 1236:2019) and WHO permissible restrict (25.0 µg/m3).

However, the variation in the concentration of $PM_{2.5}$ at the three Toll Plazas was not statistically significant ($p = 0.2$). A better attention of particulate matter depends seemed within the morning rush hours, whilst values declined to the bottom at midnight while there have been few volumes of vehicles plying the street. But the particulate awareness rose speedy to the height stage during the 5:00-10:00 hrs and 16:00-20:00 hrs intervals. This can be associated with visitors' congestion, wind course, and fined particles on the roadsides. Also, variant in vehicular density on a specific toll road may be the predominant contributing element to found differences in particulate ranges. Variations in emissions from different assets such like unpaved link roads, settlements around the Plaza's and meteorological elements (humidity) could also make contributions to the discovered differences.

It turned into additionally found that the suggest concentration of PM_{10} had been better than that of $PM_{2.5}$. The relatively high awareness in PM_{10} determined is due to the reality that vehicular emission from each exhaust and non-exhaust resources are in most cases inside the quality mode, and moreover smaller debris have greater floor place according to unit volume than larger debris consequently there may be extra debris adsorbed onto smaller particles than bigger particles for the same mass of the two.

At control locations, the highest one-hour average PM_{10} concentration was recorded at Pobiman Toll Plaza (28 µg/m^3), Accra Toll Plaza (13 µg/m^3), and Kasoa Toll Plaza (11 µg/m^3). The one-hour $PM_{2.5}$

levels followed a similar pattern as PM_{10}, with Pobiman Control Site having the highest levels (16.3 μg/m^3), Accra Control Site (8.7 μg/m^3), and Kasoa Control Site (7.3 μg/m^3). The variation in concentration of PM_{10} and $PM_{2.5}$ at the various Toll Plazas was not statistically significant ($p = 0.0004$ and $p = 0.002$ respectively). Lower values at the control sites can be attributed to wind action and vegetation cover mainly found on the roadsides.

Above all, particulate matter investigated at the Toll Plazas were all found to be higher than the Ghana Standards for Particulates Matter GS 1236:2019, Environment and Health Protection-Requirement for Ambient Air Quality Emissions of 70 μg/m^3 for PM_{10} and 35 μg/m^3 for $PM_{2.5}$ at all the Toll Plazas except Accra Toll Plaza for PM_{10} and $PM_{2.5}$ respectively. Moreover, the average PM_{10} mass concentrations and $PM_{2.5}$ mass concentrations for all three Toll Plazas exceeded the WHO Air Quality Guideline value of 50 μg/m^3 and 25 μg/m^3 for PM_{10} and $PM_{2.5}$ accordingly.

Safo-Adu et al., (2014) reported average mean of PM_{10} concentration of 86.97 μg/m^3 from November, 2011 to December, 2011 at Accra Toll Plaza. Sehgal et al., (2015) reported a daily mean of $PM_{2.5}$ of 150 μg/m^3 for highway toll plazas at Delhi. The mean levels obtained in these works are seen to be higher than that of this work of the sampling period and the traffic density especially at Delhi where traffic density is far higher than Accra.

3.2 Nitrogen Dioxide

According to Table 2 to 4, the average highest 24-hour concentration of NO_2 was observed at Pobiman Toll Plaza (229.0 μg/m^3), followed by Kasoa Toll Plaza (200.0 μg/m^3) and Accra Toll Plaza (171.7 μg/m^3). The average concentrations of NO_2 at the three Toll Plazas were generally higher than the 24-hours threshold emission level of 150 μg/m^3 for Ghana Standard 1236:2019 and WHO Permissible limit. The variation of NO_2 at the various Toll Plazas was estimated to be statistically not significant ($p=0.3$). Relatively, greater concentrations were observed in the morning and evening rush hours, while the values declined to the lowest into midnight as the density of vehicles decreased. However, the concentration of NO_2 rose quickly to a peak level (highest) during the 5:00-900 hrs and 17:00-20:00 hrs periods. At the various Toll Plazas, relatively higher levels of pollutants were recorded at the Toll Booth window area, probably because the window area was exposed to tailpipe emissions of heavy-duty trucks and also poor ventilation system in various toll cabins. The window area is highly congested with simultaneous exposure to emissions from various vehicles traveling, decelerating, or stopping to pay a Toll ticket. Minimum concentrations of NO_2 were recorded during periods of less vehicular density and also wind-blown action from the fixed fan inside the toll booths.

Also high levels of NO_2 at these locations confirming NO_2 as a tracer of the presence of traffic (Bahino et al., 2017). This suggest that traffic density appears to be one of the main sources of NO_2 emission at the Plazas. Sehgal et al., (2015) reported a daily mean of NO2 at Municipal Toll Plaza of 226.0 μg/m^3 which is close to this paper.

At control locations, average one-hour values ranged from 10.3 μg/m^3 to 18.3 μg/m^3 which remained within the Ghana Standard Limit of 250 μg/m^3. Lower values recorded can be attributed to wind action and the high speed of the vehicles plying the road.

Table 2: Concentration of air pollutants recorded after sample analysis at sampling station A

Parameters	**DAY 1**				**DAY 2**				**DAY 3**				
	Min	**Max**	**Mean**	***SD***	**Min**	**Max**	**Mean**	***SD***	**Min**	**Max**	**Mean**	***SD***	**Ave**
	ACCRA TOLL PLAZA												
PM_{10}	12	125	77.0	14.9	7	267	52.0	19.1	10	155	72.0	13.5	67.0
$PM_{2.5}$	7	117	42.5	12.2	3	195	22.5	13.9	5	130	30.0	12.6	31.7
NO_2	BDL	728	195.0	34.2	BDL	299	152.5	21.0	BDL	250	167.5	19.4	171.7
SO_2	BDL	70	12.0	5.1	BDL	90	21.0	6.9	BDL	90	19.0	4.9	17.3
CO	BDL	8.5	4.45	1.2	BDL	9.81	4.65	1.4	BDL	10.2	4.9	1.7	4.7
TVOC	BDL	0.9	2.0	0.1	BDL	1.5	2.0	0.2	BDL	0.9	2.25	0.2	2.1
	CONTROL SITE												
PM_{10}	6	68	13.0	7.5	5	45	15.0	4.9	5	30	11.0	3.4	13.0
$PM_{2.5}$	4	17	8.0	4.1	2	12	8.0	1.5	3	15	10.0	2.2	8.7
NO_2	10	14	10.0	1.4	9	20	15.0	2.1	2	20	14.0	0.9	13.0
SO_2	BDL	BDL	BDL	BDL	BDL	10	BDL	0.4	BDL	10	BDL	0.1	BDL
CO	1.31	5.05	2.45	0.8	0.8	4.5	2.37	1.2	1.2	6.5	2.65	0.8	2.5
TVOC	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

TVOC [ppm]; CO [mg/m^3]; rest of parameters [μg/m^3]; min [minimum]; max [maximum]; SD [standard deviation]; ave [average]; BDL [below detection limit]

Table 3: Concentration of air pollutants recorded after sample analysis at sampling station B

Parameters	DAY 1				DAY 2				DAY 3				
	Min	**Max**	**Mean**	***SD***	**Min**	**Max**	**Mean**	***SD***	**Min**	**Max**	**Mean**	***SD***	**Ave**
	KASOA TOLL PLAZA												
PM_{10}	14	278	110	34.9	30	183	160	25.4	17	230	145	28.6	138.3
$PM_{2.5}$	7	51	42.5	8.6	10	146	47.5	11.9	11	112	52.0	9.1	47.3
NO_2	BDL	275	270	20.0	BDL	84	140	6.3	BDL	280	190	14.2	200.0
SO_2	BDL	170	10	14.9	BDL	30	21	0.7	BDL	90	17	5.3	16.0
CO	BDL	18.17	12.88	2.8	BDL	7.14	7.2	1.0	BDL	13.5	8.1	1.9	9.4
TVOC	BDL	3.6	1.25	0.4	BDL	1.4	2.25	0.3	BDL	2.1	1.9	0.4	1.8
	CONTROL SITE												
PM_{10}	7	19	10	2.3	7	32	10	3.4	8	40	15	2.1	11.7
$PM_{2.5}$	4	13	6	1.5	3	19	7	1.6	4	21	9	0.8	7.3
NO_2	4	18	9	1.7	6	16	11	1.2	3	21	11	1.4	10.3
SO_2	BDL	BDL	BDL	BDL	BDL	10	BDL	0.1	BDL	15	BDL	0.2	BDL
CO	0.19	2.94	1.6	0.5	0.6	1.8	1.4	0.2	0.5	2.8	1.9	0.3	1.6
TVOC	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

TVOC [ppm]; CO [mg/m^3]; rest of parameters [μg/m^3]; min [minimum]; max [maximum]; SD [standard deviation]; ave [average]; BDL [below detection limit]

Table 4: Concentration of air pollutants recorded after sample analysis at sampling station C

Parameters	DAY 1				DAY 2				DAY3				
	Min	**Max**	**Mean**	***SD***	**Min**	**Max**	**Mean**	***SD***	**Min**	**Max**	**Mean**	***SD***	**Ave**
	POBIMAN TOLL PLAZA												
PM_{10}	16	380	187.0	48.2	12	196	87.0	19.3	15	185	112.0	15.7	128.7
$PM_{2.5}$	8	99	62.0	16.4	6	55	32.0	5.8	10	62	47.0	12.4	47.0
NO_2	BDL	521	205	41.3	BDL	1730	262	93	BDL	430	220	33.6	229.0
SO_2	BDL	60	10	5.9	BDL	50	15	9.2	BDL	40	15	6.3	13.3
CO	BDL	20.48	4.18	2.1	BDL	3.63	1.25	0.6	BDL	7.3	3.55	2.5	3.0
TVOC	BDL	2.5	1.5	0.2	BDL	1.3	2.25	0.2	BDL	2.8	1.9	0.5	1.9
	CONTROL SITE												
PM_{10}	11	87	29	13.2	10	55	30.0	9.5	9	42	25.0	11.4	28.0
$PM_{2.5}$	6	66	16	10.5	7	25	19.0	7.6	6	34	14.0	7.6	16.3
NO_2	10	54	19	4.2	8	45	20	4.5	8	29	16	2.8	18.3
SO_2	BDL	10	BDL	0.6	BDL	30	BDL	0.9	BDL	60	BDL	1.4	BDL
CO	1.37	6.05	2.94	1.1	0.8	3.7	2.5	0.6	0.8	4.6	2.8	0.8	2.8
TVOC	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<0.1	0.0

TVOC [ppm]; CO [mg/m^3]; rest of parameters [μg/m^3]; min [minimum]; max [maximum]; SD [standard deviation]; ave [average]; BDL [below detection limit]

3.3 Sulphur Dioxide

As presented in Tables 2 to 4, the average 24-hour concentration of SO_2 exhibited the following order: Accra Toll Plaza (17.3 μg/m^3) > Kasoa Toll Plaza (16.0 μg/m^3) > Pobiman Toll Plaza (13.3 μg/m^3). These concentrations did not exceed the Ghana standards for Sulphur Dioxide GS 1236:2019, Environment and Health Protection-Requirement for Ambient Air Quality Emissions of 150 μg/m^3. Also, daily concentrations recorded at the Toll Plazas were all within Ghana's Standard Limit. However, peak (maximum) levels recorded were also found to be lower except that at Kasoa Toll Plaza on Day 1(170.0 μg/m^3) which registered higher levels above the Ghana Standard Limit of 150.0 μg/m^3. The variation of SO_2 at the various Toll Plazas was estimated to be statistically not significant ($p = 0.6$). Sources of generation can mainly be associated with burning fuels containing sulphur by the plying vehicles and from settlement around the Plazas. However, it can also be deduced from the table that, daily mean sulphur levels from the Toll Plazas were below 25.0 μg/m^3 which suggested the vehicles using the toll plazas had good sulphur content and good engine combustion.

At Control Locations, one-hour average levels recorded were <0.01 μg/m^3 (below detection limit of the equipment) for all sites; whereas few locations registered some significant values as their maximum. All the concentrations recorded at the sampling locations were within the Ghana Standard Limit GS 1236:2019 and WHO Guideline Values of 150 µg/m^3 and 520 µg/m^3 for 24 hours and 1 hour, respectively.

3.4 Carbon Monoxide

On average, Carbon Monoxide levels from the various Toll Plazas were in descending order: Kasoa Toll Plaza (9.4 mg/m^3)> Accra Toll Plaza (4.7 mg/m^3)> Pobiman Toll Plaza (3.0 mg/m^3) as stated in Table 2 to 4. Daily CO levels ranged from minimum (below detection limit - <0.1 mg/m^3) to a maximum (10.2 mg/m^3) at Accra Toll Plaza, minimum (below detection limit - <0.1 mg/m^3) to a maximum (18.2 mg/m^3) at Kasoa Toll Plaza and minimum (below detection limit - <0.1 mg/m^3) to a maximum (20.5 mg/m^3) at Pobiman Toll Plaza (Table 2 to 4). The Toll Plazas with maximum levels were recorded at Kasoa Toll Plaza and Pobiman Toll Plaza. The levels appeared to be at maximum during the morning rush hours when people were going to work and the evening rush hours when people were returning to their various homes. These rush hours were noticed during the 5:00hrs – 9:00hrs and 16:00hrs -20:00hrs periods. Also, higher levels were recorded when Toll Booth doors were closed which is often the practice with only one side window open for collection of the Toll fee which usually cause rise of the concentration due to poor ventillation. Levels usually declined to the minimum when the density of vehicles was low and at midnight. At times, the doors were also open to improve ventilation inside the Toll Booth and also wind-blown action from the fixed fan inside the Toll Booths. The variation of CO at the various Toll Plazas was statistically significant ($p = 0.02$).

It can be noticed from the day-to-day concentration that CO levels would be as high as 14 ppm at or below the average speed of 25 km/h for moving vehicles. The linear increase in CO concentration was observed due to decrease in average speed of traffic stream at the Toll Plazas.

At the control location, a significant amount of CO concentrations was recorded which were within the Ghana Standard limit (30.0 mg/m^3).

3.5 Total Volatile Organic Compounds

The concentration of TVOCs ranged from below the detection limit (<0.1 ppm) to 1.5 ppm (Accra Toll Plaza), 3.6 ppm (Kasoa Toll Plaza), and 2.5 ppm (Pobiman Toll Plaza). On average, the TVOC levels from the various Toll Plazas were in descending order: Accra Toll Plaza (2.1 ppm)> Pobiman Toll Plaza (1.9 ppm) > Kasoa Toll Plaza (1.8 ppm). The time profile of TVOCs showed an erratic pattern during the morning and evening rush hours when the density of the vehicles plying at the Toll Centres was high. The levels were reduced to a minimum (below detection limit) when the density of the vehicles was reduced. The variation of TVOCs at the various Toll Plazas was not statistically significant ($p = 0.7$).

At control sites, all the values recorded were <0.1 ppm (below the detection limit) of the equipment. Wind action and fast-moving vehicles could account for the low level of TVOCs. Since Ghana Standard does not have a guideline limit for VOC, it cannot be compared to any guideline value. Although the present study did not analyze individual VOCs, it was observed that the aggregate of VOCs at the various Toll Plazas exceeded 4.0 mg/m^3, which is higher than the UK Guideline Limit of 0.3 mg/m^3 for instance (Hogarh et al. 2018).

3.6 Risk of Exposure Assessment

In applying Eq. 1 and Eq. 2, the concentration (mg/m^3) of pollutants was derived from the average concentration of pollutants established in Table 2 to 4; CR was assumed as 15 m^3/d, EF was 87 days/year depicting the approximate duration of working hours spent at each Toll Booth, BW was assumed to be 70 kg according to the WHO global average for a bodyweight of an adult. The risk was average over 30 years (3 decades), assuming a maximum working period of 30 years. The worst-case scenario (HI<1=>safe, HI>1=>unsafe) was assumed for this risk assessment.

Table 5 ***Hazard Quotient (HQ) of potential exposure at Toll Booth facilities***

Parameter	Accra TollPlaza	Kasoa Toll Plaza	Pobiman Toll Plaza
PM_{10}	6.8×10^{-2}	1.4×10^{-1}	**1.3×10^{-1}**
$PM_{2.5}$	4.0×10^{-2}	6.0×10^{-2}	**6.0×10^{-2}**
NO_2	1.8×10^{-1}	2.0×10^{-1}	**1.9×10^{-2}**
SO_2	$1.8\ 10^{-2}$	1.6×10^{-2}	**1.4×10^{-2}**
CO	2.4×10^{-2}	4.8×10^{-2}	**1.5×10^{-2}**
TVOC	8.2×10^{-1}	7.0×10^{-1}	**7.4×10^{-1}**
	$\Sigma(HI)=$ 1.15	$\Sigma(HI)=$ 1.18	**$\Sigma(HI)=$ 9.8×10^{-1}**

As shown in Table 5, the HQ for the various pollutants at each Plaza were generally low (less than 1), which designates that the individual pollutants exposed by the attendants may not constitute adverse environmental health risk over a three-decade (Pinto et al. 2014). Among the pollutants, the highest risk was linked with PM_{10} (at Kasoa and Pobiman Toll Plaza), NO_2 (at Accra and Kasoa Toll Plaza), and TVOCs (at Accra, Kasoa, and Pobiman Toll Plaza). For PM_{10}, the risk ranged from 1.3×10^{-1} to 1.4×10^{-1} at Kasoa and Pobiman Toll Plaza which implies approximately one (1) person out of ten at Kasoa and Pobiman Toll Plaza may suffer Particulate Matter morbidity from working at Kasoa and Pobiman Toll Plaza. For NO_2, the risk ranged from 1.8 x 10^{-1} to 2.0 x 10^{-1} at Accra and Kasoa Toll Plaza which implies approximately 2 persons out of ten may suffer Nitrogen Dioxide morbidity from working at Accra and Kasoa Toll Plaza. For TVOCs, the risk ranged from 7.0 x 10^{-1} to 8.2 x10^{-1} at Accra, Kasoa, and Pobiman Toll Plaza which implies approximately seven (7) to eight (8) persons out of ten may suffer TVOCs morbidity from working at Accra, Kasoa and Pobiman Toll Plaza. Applying Eq. 3, the HI which is an aggregate of the risks from the individual pollutants was estimated as 1.15, 1.18, and 9.8 x 10^{-1} for Accra, Kasoa, and Pobiman Toll Plaza accordingly (Table 5). Although the individual HQ for the worst-case scenario was (HQ <1=>safe), the aggregate of the individual pollutants HI at the Toll Plazas was (HI>1=>unsafe) (Pinto et al. 2014). Risks of 1.2 and 0.98 represent approximately 1 morbidity per person at each Toll Plaza.

4 Conclusions

A study conducted in the Greater Accra Region of Ghana examined the Indoor Air Quality (IAQ) at various Toll Plazas along major highways. The results indicated that the concentration of Particulate Matter (PM) and Nitrogen Dioxide (NO_2) exceeded the Ghana Standard Limit and World Health Organization (WHO) Guideline Limits. However, Sulphur Dioxide (SO_2), Carbon Monoxide (CO), and Total Volatile Organic Compounds (VOCs) exhibited lower concentrations. The levels of pollutants varied depending on the density of vehicles on the highways, with higher concentrations observed during morning, daytime, and evening rush hours, while reaching a minimum during midnight. Unpaved areas surrounding the Toll Plazas, commercial activities, and wind-blown fine particles contributed significantly to the concentration of particulate matter. Prolonged exposure to elevated levels of pollutants could have adverse health effects.

Although the Hazard Quotient (HQ) for these pollutants at the Toll Plazas was relatively low (ranging from 1.3 x 10^{-1} to 8.2 x 10^{-1}, indicating safety), the combined risk, represented by the Hazard Index (HI), exceeded 1.0 (indicating unsafety) at Accra, Kasoa, and Pobiman Toll Plazas, with estimated values of 1.15, 1.18, and 9.8 x 10^{-1}, respectively.

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