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Meteorological and Air Pollution Assessment from Road Use and Construction in the Eastern and Greater Accra Regions (Ghana)

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Abstract
The study identified the impacts of air pollutants and their relationships with meteorological parameters. Pollutants generated from road construction and use compared with WHO and Ghana Standards Authority (GSA) guidelines revealed the median of PM_{10} (76µg/m^3), $PM_{2.5}$ (26.1µg/m^3), NO_2 (36µg/m^3), SO_2 (236 µg/m^3), noise (75dBA) at Somanya sampling location were above the WHO guidelines for air quality. Whiles PM_{10}, $SO_{2,}$ and noise were above the (GSA) permissible limits. The Mataheko location had median values of PM_{10} (100.4 µg/m^3), $PM_{2.5}$ (24.9µg/m^3), NO_2 (41.0 µg/m^3), SO_2 (26 µg/m^3), noise (75.5 dBA) above the WHO limits, whereas only noise and PM_{10}, were above the GSA limits for ambient air quality. Construction activities released $PM_{10,}$ $PM_{2.5}$, NO_2, $SO_{2,}$ and noise above WHO and GSA limits. Though the quantities detected are not directly comparable to air quality recommendations, which are based on 24-hour or annual averages, they raise concerns about public health and policy.

Keywords: road, road construction, air pollutants, atmospheric parameters, Ghana
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1. Introduction

The importance of roads in the twenty-first century cannot be overemphasized, typically nurturing socio-economic development. Ghana has been keen to utilize adequate transportation infrastructure, especially the road network, to shift towards industrial production independence. However, Environmentalists' have a widely held view that constructing roads is a considerable interference with ecological habitats, ecosystem functions, and natural resources such as forests. However, in contrast to this view, urban planners and economists view roads as the best avenue for exploring interior regions for new business prospects. Notably, Ghana's environmental management department and conservation biologists have cited claims that the rapid increase and use of road works have had adverse effects on the ecological balance. Typically, the road works are most often constructed with complete disregard for wildlife habitats, animals' migration routes, seasonal dispersal patterns, and changeable impact on animals from noise. Therefore, road infrastructure construction and use have led to physical disturbance and environmental depletion, such as noise and chemical pollution.

Sadly, according to the most recent data available, Ghana's air quality is considered unsafe. $PM_{2.5}$ related deaths in Ghana increased from 3500 in 1990 to 12,200 in 2018 and 12,500 in 2019. (Health Effects Institute, 2020). Additionally, Ghana and its capital city Accra rank second in annual average $PM_{2.5}$ concentrations of 26.9 (µg/m^3), trailing only Mali's 37.9 (µg/m^3) (IQAir, 2021). Accra and major cities and villages consistently experience high levels of air pollution caused by vehicular exhaust fumes generated from road traffic. The roads are clogged with ancient, rickety vehicles, some of which run on sulfur or nitrogen-rich fuels, trapped in heavy traffic on sunny days with unusually high temperatures. Additionally, resuspended dust from unpaved and dusty roads, which are a common phenomenon in Ghana; also, the dry and dusty northeasterly trade wind, 'harmattan,' that blows from the Sahara across West Africa and into the Gulf of Guinea is a significant contributor of particulates to the atmosphere.

Previous air quality studies conducted in Ghana have focused on the nature and amount of pollutants emitted from bush fires, emission from motor exhausts, as well as emission from both domestic and industrial activities, which constitutes ambient air pollution (Aboh *et al*., 2009; Aboh & Ofosu, 2010; Dionisio *et al*., 2010; Dotse *et al*., 2012; Ofosu *et al*., 2015). Other studies narrowed on the use of the road itself (Atiemo *et al*., 2012; Boahene *et al*., 2019; Kylander *et al*., 2003; Safo-Adu *et al*., 2014). There also seem to be a much focus on particulates (PM_{10} and $PM_{2.5}$). In contrast, effects from nitrogen oxides, sulfur oxides, volatile organic compounds (VOC), ozone (O_3), carbon-monoxide (CO), carbon dioxide (CO_2), and noise are evident; their effects are harmful to humans and the environment and need timely, enormous research and remedy.

However, the current inadequate studies on road environmental issues are also a cause for concern. More recent attention has focused on-road use pollution with a paucity of literature on road construction. This study assessed and compared the nature and amount of pollutants generated from road construction and use activities and meteorological data with the World Health Organization (WHO) (WHO, 2021) and Ghana Standard Authority (GSA) guidelines. A statistical evaluation of the relationships of eight (8) air pollutants (Noise, PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, O_3, CO_2) and three (3) meteorological parameters (temperature, relative humidity, wind speed) at two different sampling locations in the Eastern and Greater Accra regions of Ghana, and road construction sampling locations in the Eastern region of Ghana. The difference in concentration of pollutants between the different sampling locations and sampling days and the relationship between pollutants and traffic density was also evaluated.

The goal is to unravel the impact of air pollutants on the environment and the relationships between air pollutants and meteorological parameters since they have a significant impact on ambient air pollution because they affect the emissions, transport, production, and deposition of air pollutants both directly and indirectly (Zhang, Wang, Hu, Ying, & MingHu, 2015). The study's findings will also inform the relevant stakeholders in environmental management about the amount of pollutants generated from road construction and use activities and how it can affect policy decisions and air quality management in general.

2. Methods and data

2.1. Description of the study locations

Road construction data used in the study were collected from the Fanteakwa North district (Obooho, Duapolice). Road use data were collected from Somanya and Mataheko of the Yilo Krobo and Ningo Prampram Municipality. As shown in (Figures. 1 and 2).

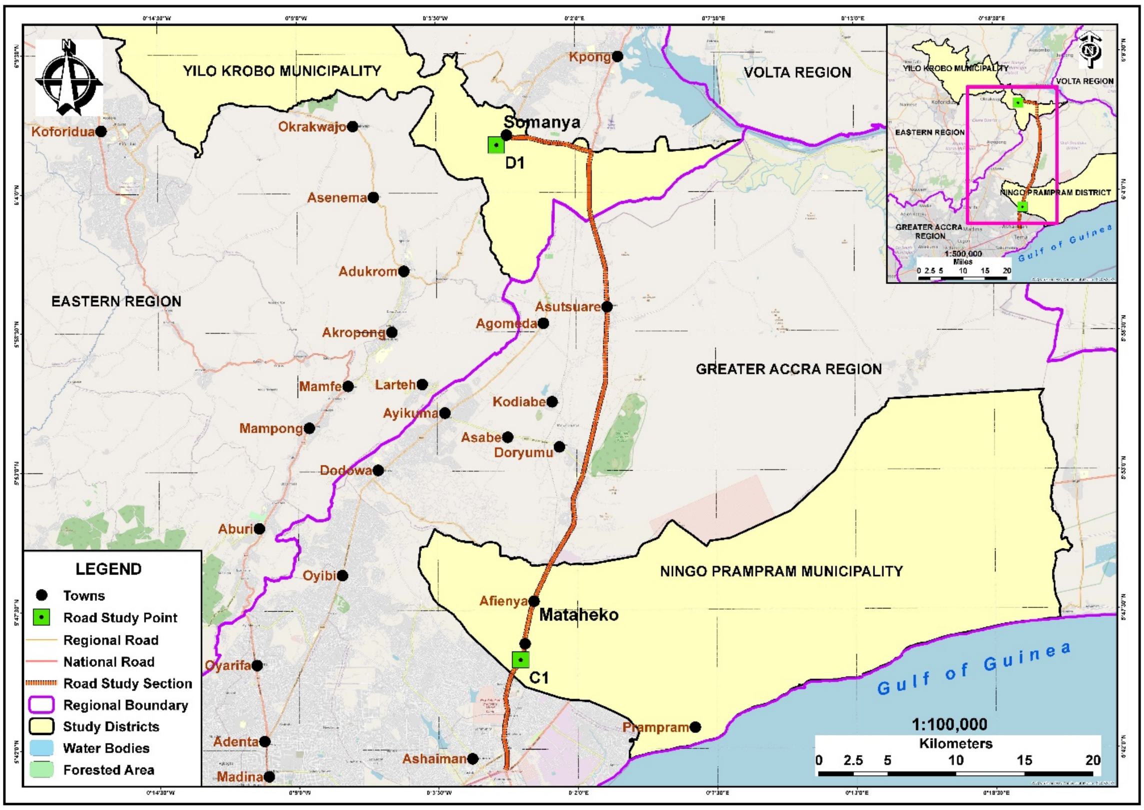

Figure 1. A Map of Ghana Showing the Yilo and Ningo-Prampram Municipality and Road Use Sampling Sites.

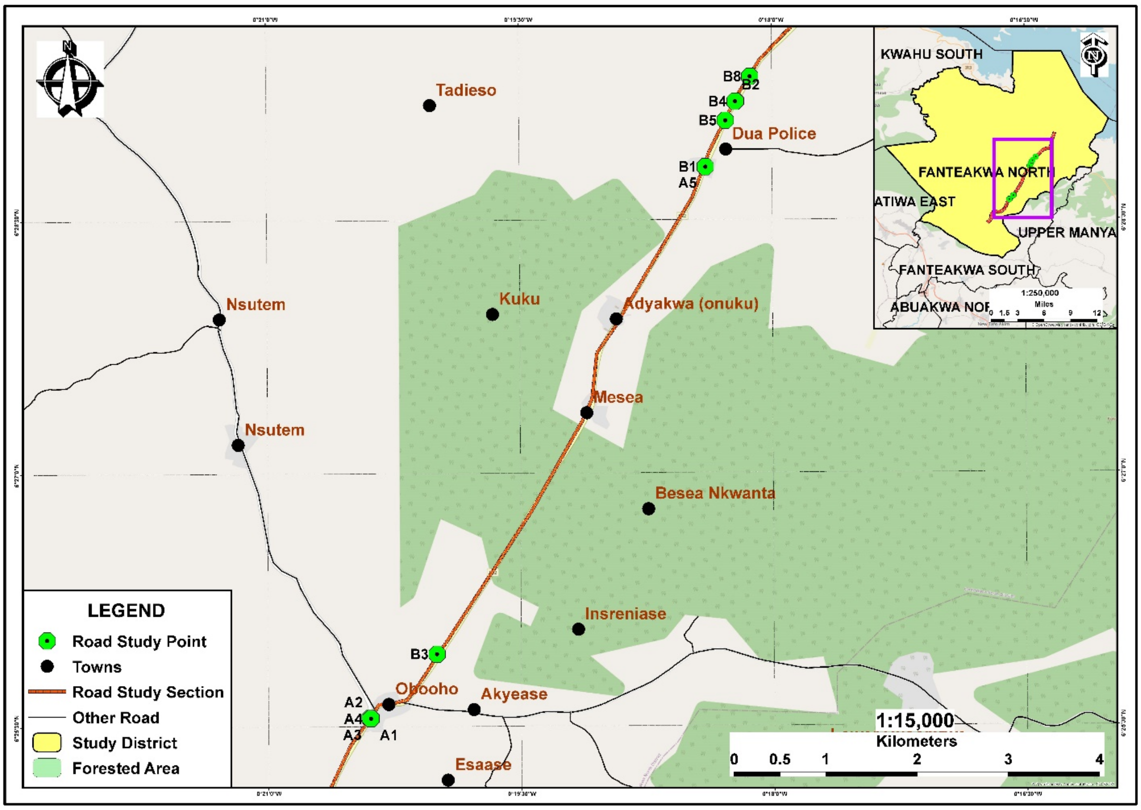

Figure 2. A map of Ghana showing Fanteakwa North district and road construction sampling sites

2.2. Sites for measurement

Somanya's location was less busy compared to Mataheko. Somanya's sampling location was set up on the main road, which goes through the Somanya township. The site can be classified as mixed-use, characterized by residential and commercial areas, health facility, offices, and a law court. Similarly, the Mataheko sampling location was set up on the (Tema–Akosombo) highway, opposite the Emefs Hillview Estates police station. The site depicts a mixed-use environment, having a residential, office, and commercial setting. These sites selected were based on the extensive commercial activities around the road and the busy nature of the place.

The road construction sampling was done during the partial reconstruction of the Begoro-Mpaem roads (KM 0.00 – 38.00). Samples were taken from two (2) different towns (Oboohu and Duapolice) because the construction companies' activities were centered in these two towns at the time of sampling. The construction site was chosen because it was a new road under construction. Therefore, all the different stages of road construction will be assessed and data collected as depicted in (Table 1). Also, (Table 2) provides the sampling locations and their coordinates.

Table 1. Different Activities Depicting Sampling During Road Construction

Activity A	Construction of curb and gutter
Activity B	Construction of curb and gutter
Activity C	Construction of curb and gutter Petrol concrete mixer started at 11:20 am
Activity D	1. The use of excavating equipment to cut into the earth, break and remove rocks in the earth 2. Spread earth and soil along the roads future path
Activity E	1. The use of excavating equipment to cut into the earth, break and remove rocks in the earth 2. Spread earth and soil along the roads future path
Activity F	1. The use of excavating equipment to cut into the earth, break and remove rocks in the earth 2. Spread earth and soil along the roads future path
Activity G	1. The use of excavating equipment to cut into the earth, break and remove rocks in the earth 2. Spread earth and soil along the roads future path
Activity H	1. The area adjacent to the road is cleansed of all vegetation, including trees, shrubs, and bushes 2. Grader levels and smooth the road surface 3. Roller levels the surface
Activity I	Grader levels and smooth the surface
Activity J	Roller levels the surface
Activity K	1. Grader levels and smooth the surface 2. Roller levels the surface
Activity L	1. Roller levels the surface 2. Water sprayed to reduce dust at 2:00 – 2:40 pm
Activity M	1. Excavator destruction of the planned road's path 2. The areas adjacent to the road is cleansed of all vegetation, including trees, shrubs, and bushes
Activity N	1. Excavator destruction of the planned road's path 2. The areas adjacent to the road is cleansed of all vegetation, including trees, shrubs, and bushes
Activity O	1. Excavating equipment spread earth and soil along the roads future path 2. The areas adjacent to the road is cleansed of all vegetation, including trees, shrubs, and bushes 3. Concrete mixer used in the construction of Culverts and drains
Activity P	Excavator digs into the earth, spread earth and soil to level the surface and breaks rocks.
Activity Q	Tipper trucks hip sand and gravel adjacent the road.

Table 2. Sampling Location and their Coordinates

Sampling location	Definition	Geographical location	
		Latitude	Longitude
Somanya	Road use	6° 5' 53.23" N	0° 1' 6.86" W
Mataheko	Road use	5° 45' 32.26" N	0° 0' 15.64" W
Oboohu	Road construction	6° 28' 48.74" N	0° 20' 23.53" W
Oboohu	Road construction	6° 25' 32.96" N	0° 20' 23.6" W
Oboohu	Road construction	6° 25' 33" N	0° 20' 19.16" W
Oboohu	Road construction	6° 25' 32.91" N	0° 20' 23.66" W
Oboohu	Road construction	6° 28' 48.74" N	0° 18' 23.67" W
Duapolice	Road construction	6° 28' 48.74" N	0° 18' 23.67" W
Duapolice	Road construction	6° 29' 12.07" N	0° 18' 12.88" W
Duapolice	Road construction	6° 25' 55.71" N	0° 20' 0.07" W
Duapolice	Road construction	6° 5' 52.4" N	0° 1' 6.69" W
Duapolice	Road construction	6° 29' 11.96" N	0° 18' 13" W
Duapolice	Road construction	6° 29' 5.23" N	0° 18' 16.49" W
Duapolice	Road construction	6° 29' 42.22" N	0° 17' 48.37" W
Duapolice	Road construction	6° 29' 42.2" N	0° 17' 48.37" W
Duapolice	Road construction	6° 29' 20.81" N	0° 18' 7.77" W

2.3 *Instrumentation*

The air pollutants were measured using Aeroqual Series 500 Handheld Monitor with corresponding class one (1) gas sensor heads for (PM10 and PM2.5), Ozone (O3), Sulphur dioxide (SO2), Nitrogen dioxide (NO2), Carbon monoxide (CO) and Carbon dioxide (CO2). Likewise, the meteorological parameters (air temperature, relative humidity, wind speed) and noise were measured using a PCE-EM 883 environmental meter.

2.4 Measurements

The Aeroqual series, 500 handheld monitors, were set up at the height of 1.5m above the ground level and a distance of 1.5m from the edge of the road. Whereas the PCE-EM 883 environmental meter was mounted 0.9m apart, on a tripod stand about one point five (1.5m) meters from the road and set at one point five meters (1.5m) above the ground with the microphone pointing at the perceived sound source.

The ambient air quality measurements were carried out for a period of twelve (12) hours at the two (2) receptor areas (Somanya and Mataheko) for road use. Data were logged automatically every minute for twelve (12) hours (6:00 am to 6:00 pm). Monitoring was done from Friday, 26th February 2021, to Sunday, 14th March 2021, at Somanya, totaling eighteen (18) days, and from Monday, 17th May 2021, to Sunday, 6th June 2021, at Mataheko, making a total of eighteen (18) days. All data were collected for six (6) days in a week (Monday, Tuesday, Wednesday, Friday, Saturday, and Sunday). Road construction sampling commenced from Monday 22nd March 2021 to Saturday 17th April 2021, making seventeen (17) days.

Two (2) different pollutants were measured for each day, except for particulates, where the particulate matter sensor could measure PM10 and PM2.5 at the same time added to another pollutant. (Table 3) shows the weekly schedule for air quality measurements.

3.0 Results and Discussions

3.1. Data overview

(Table 4) shows the twelve-hour median, minimum, maximum, conversion of units to appropriate standards, WHO and GSA permissible limits for the air pollutants and noise at the two road use sampling locations for the entire sampling period.

Table 4. Statistical summary of the 12-hours median, minimum, maximum concentrations of windspeed (m/s), surface temperature (°C), relative humidity (%), PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, O_3, CO_2, Noise and traffic volume (q, h^{-1}) during the entire sampling period. Units mg/m^3 for (PM_{10}, $PM_{2.5}$); ppm for all gaseous pollutants; dBA for noise.

MP	Median	Minimum	Maximum	Conversion	WHO	GSA
Somanya sampling location						
Temperature	34.0	24.1	49.4			
Relative Humidity	50.90	25.6	92.3			
Windspeed	00.2	00.0	04.0			
Air Pollutants and Traffic Volume						
Noise	75.2	30.2	104.9		70	60
PM_{10}	0.0677	0.0040	0.3530	76	45	70
$PM_{2.5}$	0.0261	0.0079	0.2444	26.1	15	35
CO	0.462	0.00	9.230	0.5	4	-
NO_2	0.0193	0.0037	0.0685	36	25	150
SO_2	0.0900	0.00	0.61	236	40	50
O_3	0.0039	0.00	0.0493	8	100 (8hrs)	-
CO_2	395	374	520		-	-
Traffic Volume	816	636	985			
Mataheko sampling location						
Temperature [°C]	31.60	23.9	41.8			
Relative Humidity [%]	61.45	33.2	96.4			
Windspeed [m/s]	01.30	00.0	07.1			
Air Pollutants and Traffic Volume						
Noise	75.55	50.9	101.5		70	60
PM_{10}	0.1004	0.0130	0.4320	100.4	45	70
$PM_{2.5}$	0.0249	0.0023	0.1850	24.9	15	35
CO	1.098	0.00	7.528	1.1	4	-
NO_2	0.0219	0.000	0.0679	41.0	25	150
SO_2	0.0100	0.00	0.26	26	40	50
O_3	0.00615	0.00	0.0384	12	100 (8hrs)	
CO_2	429	403	516			
Traffic Volume	1350	917	1457			

Note: (MP: meteorological parameters). Conversion, 24 hour WHO and GSA standards are in µg/m^3, CO is in mg/m^3.

Table 5. Statistical summary of the minimum, maximum, mean concentrations of surface temperature (Temp, °C), relative humidity (RH, %), wind speed (WS, m/s). PM$_{10}$, PM$_{2.5}$, CO, NO$_2$, SO$_2$, O$_3$, CO$_2$, and Noise during the entire sampling period. Units mg/m^3 for (PM$_{10}$, PM$_{2.5}$); ppm for all gaseous pollutants; dBA for noise.

MP	Minimum	Maximum	Median	Conversion	WHO	GRA
Activity A						
Temp	27.0	34.2	31.0			
RH	50.2	72.9	58.60			
WS	00.7	05.5	02.0			
Air Pollutants						
Noise	44.6	87.9	58.60		66	60
PM$_{10}$	0.0123	0.0448	0.0927	92.7	45	70
PM$_{2.5}$	0.0116	0.0448	0.0240	24.0	15	35
CO	0.00	10.113	0.078	0.089	4	
Activity B						
Temp	24.6	32.4	30.1			
RH	51.1	76.9	57.90			
WS	00.0	05.0	01.30			
Air Pollutants						
Noise	50.90	89.70	62.00		66	60
NO$_2$	0.008	0.035	0.0212	40.0	25	150
SO$_2$	0.00	0.17	0.080	210	40	50
Activity C						
Temp	26.3	31.7	29.30			
RH	49.5	60.8	55.30			
WS	00.3	05.2	01.50			
Air Pollutants						
Noise	49.6	102.7	68.4		66	60
O$_3$	0.00	0.0122	0.0039	8	100(8hrs)	
CO$_2$	396	545	407			
Activity D						
Temp	27.3	31.5	29.80			
RH	53.0	72.1	59.55			
WS	00.2	04.2	02.15			
Air Pollutants						
Noise	51.0	85.1	72.35		66	60
PM$_{10}$	0.0168	0.1107	0.0444	44.4	45	70
PM$_{2.5}$	0.0052	0.0269	0.0107	10.7	15	35
CO	0.00	1.3333		0.1	4	
Activity E						
Temp	29.3	34.4	32.65			
RH	39.6	56.7	44.25			
WS	00.0	02.4	00.45			
Air Pollutants						
Noise	43.6	88.0	67.60		66	60
NO$_2$	0.00	0.0265	0.0190	36	25	150
SO$_2$	0.00	0.13	0.0250	66	40	50
Activity F						
Temp	26.3	30.5	28.40			
RH	61.4	82.5	67.50			
WS	00.0	02.8	01.20			
Air Pollutants						
Noise	64.0	86.0	77.90		66	60
O$_3$	0.00	0.0029	0.0007	1.0	100(8hrs)	
CO$_2$	389	430	396			

MP	Minimum	Maximum	Median	Conversion	WHO	GRA
Activity G						
Temp	29.8	33.90	31.50			
RH	37.3	66.1	51.50			
WS	00.0	03.1	00.80			
Air Pollutants						
Noise	40.3	87.1	65.80		66	60
NO_2	0.0013	0.0236	0.0133	25	25	150
SO_2	0.00	0.28	0.030	79	40	50
Activity H						
Temp	30.1	36.6	32.60			
RH	39.2	65.4	49.60			
WS	00.0	03.0	01.10			
Air Pollutants						
Noise	39.1	85.8	64.6		66	60
O_3	0.000	0.0057	0.0025	5.0	100(8hrs)	
CO_2	388	423	395			
Activity I						
Temp	31.3	32.5	33.05			
RH	35.0	60.1	49.95			
WS	00.0	03.1	00.20			
Air Pollutants						
Noise	36.6	84.2	49.05		66	60
PM_{10}	0.1860	0.6108	0.2548	254.8	45	70
$PM_{2.5}$	0.0168	0.1144	0.04345	43.45	15	35
CO	0.043	0.1217	0.0570	0.065	4	
Activity J						
Temp	27.4	36.8	32.65			
RH	41.2	70.2	56.15			
WS	00.0	03.70	01.25			
Air Pollutants						
Noise	44.3	84.7	70.55		66	60
PM_{10}	0.1908	0.5054	0.24125	241.25	45	70
$PM_{2.5}$	0.0420	0.0848	0.05405	54.05	15	35
CO	0.00	4.0220	0.2230	0.255	4	
Activity K						
Temp	31.7	35.7	33.35			
RH	48.1	60.7	54.10			
WS	00.0	02.6	01.55			
Air Pollutants						
Noise	40.2	89.8	52.55		66	60
NO_2	0.0020	0.0268	0.0175	33	25	150
SO_2	0.00	0.04	0.0063	3	40	50
Activity L						
Temp	30.1	33.7	31.60			
RH	45.0	66.6	55.70			
WS	00.0	04.3	02.6			
Air Pollutants						
Noise	44.4	90.2	74.2		66	60
NO_2	0.00	0.0141	0.0056	11	25	150
SO_2	0.00	0.32	0.160	419	40	50

MP	Minimum	Maximum	Median	Conversion	WHO	GRA
			Activity M			
Temp	31.4	35.7	32.7			
RH	40.6	48.2	45.10			
WS	00.1	05.1	00.25			
Air Pollutants						
Noise	34.9	90.0	64.2		66	60
O_3	0.00	0.0022	0.0002	0.0001	100(8hrs)	
CO_2	390	425	408			
			Activity N			
Temp	30.90	36.60	32.20			
RH	43.2	65.9	58.90			
WS	00.1	04.2	01.1			
Air Pollutants						
Noise	50.9	84.0	71.6		66	60
NO_2	0.0052	0.0269	0.01150	22	25	150
SO_2	0.00	1.166	0.0440	115	40	50
			Activity O			
Temp	27.60	33.60	30.60			
RH	43.3	69.8	59.30			
WS	00.1	08.3	02.40			
Air Pollutants						
Noise	59.2	80.3	69.50		66	60
PM_{10}	0.0051	0.1528	0.03170	31.7	45	70
$PM_{2.5}$	0.0027	0.0214	0.00770	7.7	15	35
CO	0.00	2.005	0.0620	0.1	4	
			Activity P			
Temp	29.5	31.6	30.10			
RH	58.1	66.4	63.90			
WS	00.0	01.2	00.95			
Air Pollutants						
Noise	86.6	93.1	89.40		66	60
O_3	0.00	0.0006	0.00012	0.0001	100(8hrs)	
CO_2	453	491	484			
			Activity Q			
Temp	29.4	37.8	33.0			
RH	42.4	66.9	51.3			
WS	0.0	04.7	00.60			
Air Pollutants						
Noise	43.0	91.9	71.40		66	60
NO_2	0.00	0.0161	0.0067		25	150
SO_2	0.00	0.16	0.040		40	50

Note: (MP: meteorological parameters). Conversion, 24 hour WHO and GSA standards are in $\mu g/m^3$, CO is in mg/m^3.

(Table 5) also shows the minimum, maximum, median, conversion of units to appropriate standard, WHO, and GRA permissible limits for the entire period of road construction activities sampling.

At the Somanya sampling location, the median of noise (75dBA), PM_{10} (76$\mu g/m^3$), $PM_{2.5}$ (26.1 $\mu g/m^3$), NO_2 (36 $\mu g/m^3$), and SO_2 (236 $\mu g/m^3$) were slightly above the WHO acceptable guideline limit except for SO_2, which was almost six (6) times that quantity. Further, concerning the GSA limits, noise (75dBA), PM_{10} (76$\mu g/m^3$), and SO_2 (236 $\mu g/m^3$) were above the limits. Quite similar to the Somanya location, in contrast, the Mataheko location recorded median values for noise (75.5 dBA), PM_{10} (100.4 $\mu g/m^3$), $PM_{2.5}$ (26.1 $\mu g/m^3$), NO_2 (36 $\mu g/m^3$), which were slightly above the WHO permissible limit except for PM_{10}, which was twice as high. Also, only noise and PM_{10} were above the GSA acceptable limits.

These results may be explained by the fact that particulate matter sources include particles produced after the combustion of fossil fuels and biomass, for example, in diesel and petrol engines. These are typically constituted primarily of carbon, both in its elemental form and as low-volatile organic compounds which could be suspended in the atmosphere. Also, fly ash is a significant source of non-carbonaceous particles, which are released into the atmosphere by the combustion of a fuel like coal. Mechanical procedures such as quarrying can also produce small rock fragments that can be carried into the sky by the wind. Construction and demolition can produce coarse particles as well. The high levels of particles recorded in the study resulted from wind-driven sand and tiny rock particles carried about in the air. As observed in the location, there were several untarred areas adjacent to the road under investigation. This was typically serious at the Mataheko location, where public transport drivers moved off the main tarred road into the untarred part of the road to pick up passengers. The movement of vehicles on unpaved roads has contributed to significantly high levels of particulates.

NO_2 levels in urban air are mainly from petrol and diesel engines when the nitrogen in fuels is converted to NO_2. Another source of NO_2 production is the combination of nitrogen and oxygen in the air at very high temperatures to form NO_2. Somanya's location recorded a maximum temperature of 49.4°C (Table 4). These two sources could have contributed to the high quantity of NO_2 at these two sampling locations. Furthermore, SO_2 levels from urban traffic monitoring could be from the amount of sulfur in the fuel used. SO_2 is produced when the sulfur in fuels is burned to SO_2. This could mean the fuel being used could have a sufficient concentration of sulfur in them. Lastly, the noise characterized by road use is mainly from the honk of cars. Many car drivers honk unnecessarily even when they are not supposed to. Some motorbikes make extremely high noise from their engines when on top speed. Heavy-duty tanker drivers are also fond of making noise when not necessary. Other sources include ambulance services and official motorcades as well.

The construction sampling A recorded median of PM_{10} (92.7µg/m^3), $PM_{2.5}$ (24.0 µg/m^3), which were slightly above the WHO acceptable limit, further, concerning the GSA limits, PM_{10} (792.7µg/m^3 was above the limits. The construction sampling B recorded a median of NO_2 (40 µg/m^3) and SO_2 (210 µg/m^3). They were above the WHO acceptable limit. Further, with the GSA limits, SO_2 (210 µg/m^3) was above the limits. Plus, construction sampling C recorded a median of noise (68.4 dBA) above the GSA limit. The construction sampling D recorded a noise median (72.4 dBA) above the WHO and GSA limits. The construction sampling E recorded a median of noise (67.6dBA), NO_2 (36 µg/m^3), and SO_2 (66 µg/m^3), which were slightly above the WHO acceptable limit. Further, concerning the GSA limits, noise (67.6 dBA) and SO_2 (66 µg/m^3) were above the limits. The construction sampling F recorded a noise median (77.9 dBA) above both the WHO and GSA acceptable limits.

The construction sampling, I recorded a very high median of PM_{10} (254.8 µg/m3) and $PM_{2.5}$ (43.45 µg/m3) above the acceptable limits of WHO and GSA. Also, construction sampling G recorded a median of SO_2 (79 µg/m3) above the WHO and GSA limits for NO_2. Additionally, construction sampling J recorded a median of noise (70.6 dBA), PM_{10} (241.25µg/m^3), $PM_{2.5}$ (54.05 µg/m^3), the exceptionally high values of PM_{10}, and all pollutants were above the WHO and GSA standards. The construction sampling K recorded a median of NO_2 (33 µg/m^3) above the WHO limits. The construction sampling L recorded a median of noise (74.2 dBA) and SO_2 (419 µg/m3) above the WHO and GSA limits. Further, the construction sampling N recorded a median of noise (71.6 dBA) and SO_2 (115 µg/m3) above the WHO and GSA limits. The construction sampling O recorded a median of noise (69.5 dBA) above the GSA limit. The construction sampling P recorded a median of noise (89.4 dBA) above the WHO and GSA limit. The construction sampling Q recorded a median of noise (71.4 dBA) SO_2 (105 µg/m^3) above the WHO and GSA limits.

These results corroborate the findings of previous work by Font *et al.* (2014); the study found NO_2 concentration exceeded the EU limit value after the road development indicating a remarkable deterioration in air quality. Fuller & Green (2004) also confirmed that roadworks could increase daily mean PM_{10} measurements above the EU Limit Value of 50 µg/m^3. Azami *et al.* (2016) also assessed the long-term impacts of PM_{10} and $PM_{2.5}$ particles from construction works on surrounding areas; the results show that daily mean concentrations of PM_{10} exceeded the European Union target limit value of 50 µg/m^3.

All activities of the construction process released pollutants that exceeded WHO and GSA limits, as long as they have to do with machinery where fuel has to be used. Also, the sound is produced from machinery when these activities are being executed. PM_{10} and $PM_{2.5}$ were produced mainly due to heavy trucks and machinery on unpaved roads and public transportation. There were also cases of breaking rocks and aggregating sand particles into the atmosphere. The SO_2 and NO_2 are from the fuel being used, which is diesel. Noise readings were basically from machinery and heavy trucks during the construction activities.

3.2. Mann-Whitney U test for Meteorological and Air Pollutants (Comparing Mataheko and Somanya Locations)

The distribution of pollutants and meteorological parameters were different as assessed by visual inspection of boxplots (Figure 3). Relative humidity (RH) and wind speed (WS) were statistically significantly higher at Mataheko except for temperature compared to Somanya. Pollutants were substantially higher at Mataheko for all pollutants except for SO_2, whereas O_3 and CO_2 were not different.

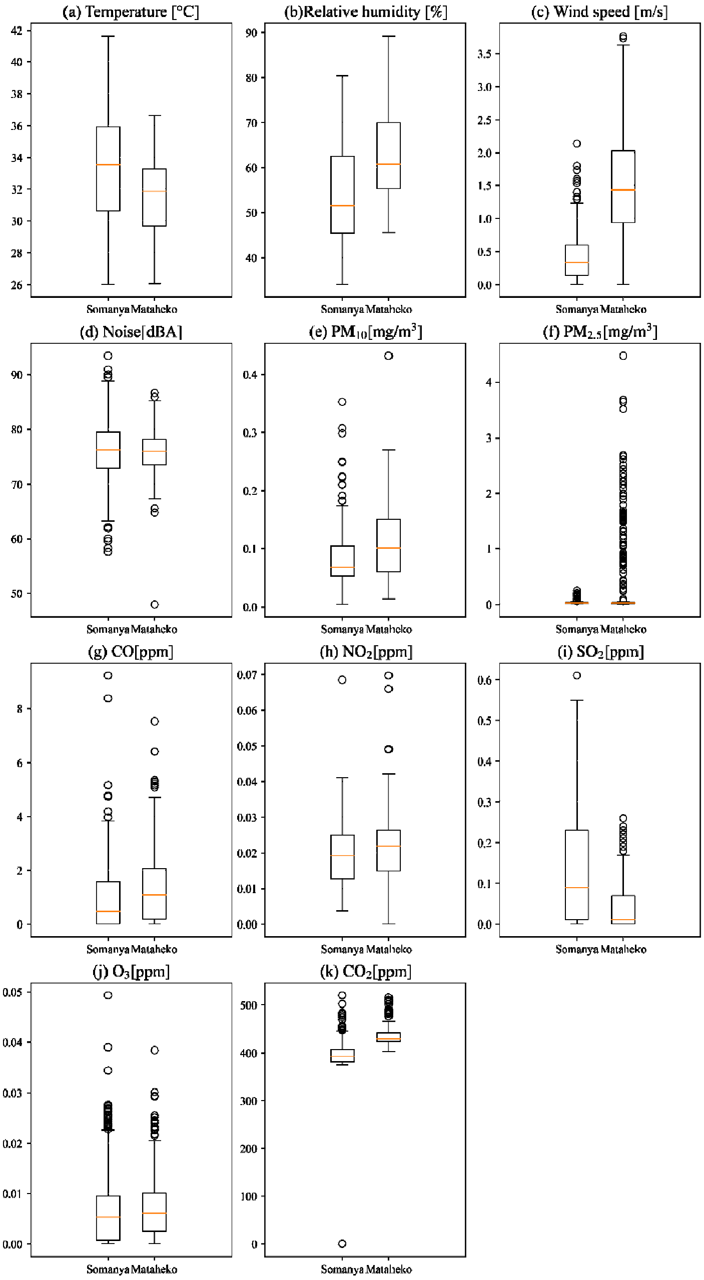

Figure 3. Boxplots of 12hour meteorological and air pollutants across the two sampling sites.

3.3. The Difference in the median Between the Different Days of Sampling (Somanya and Mataheko)

The distribution of meteorological parameters and air pollutants was not similar for all sampling days at the Somanya location. The Mataheko location also had meteorological parameters not similar for all sampling days. However, noise, carbon monoxide (CO), and sulphur dioxide (SO_2) values didn't show any statistically significant difference.

3.4 Correlation between air pollutants and meteorological parameters (road use and construction)

Spearman's rank-order correlations were run to examine the relationships between meteorological factors and air pollutants. At the Somanya location, temperature was positively correlated with PM_{10}, $PM_{2.5,}$ SO_2 ($p < .001$), and NO_2, O_3 ($p < .005$). It was negavitely correlated with CO_2 ($p < .001$) and noise ($p < .005$). RH was positively correlated with noise and CO_2 ($p < .001$) and negatively correlated with PM_{10}, $PM_{2.5,}$ $CO_{2,}$ SO_2, O_3 ($p < .001$). Wind speed was positively correlated with noise ($p < .001$) and SO_2 ($p < .005$) (Table 6). Mataheko location also showed similar trends, temperature was positively correlated with PM_{10}, $PM_{2.5,}$ $SO_{2,}$ NO_2 ($p < .001$) and CO ($p < .005$). And negavitely correlated with CO_2 and noise ($p < .001$). RH was positively correlated with noise and CO_2 ($p < .001$) and negatively correlated with PM_{10}, $PM_{2.5,}$ $CO_{2,}$ SO_2 ($p < .005$), O_3 ($p < .005$). Moreover, WS was positively correlated with PM_{10}, $PM_{2.5}$, SO_2 ($p < .001$) and CO ($p < .005$) and negatively correlated with CO_2 ($p < .001$) (Table 7).

Table 6. Statistical summary of spearman correlation coefficient values for road use activities at Somanya sampling location. Temperature (Temp, °C), relative humidity (RH, %), wind speed (WS, m/s). PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, O_3, CO_2, and Noise during the entire sampling period.

	Temp	RH	WS	Noise	PM_{10}	$Pm_{2.5}$	CO	NO_2	SO_2	O_3	CO_2
Temp	1.000	__-.919**__	0.38	__-.062*__	__.281*__	__.187**__	.010	__-.096*__	__.791**__	__.108**__	__-.367**__
RH	__-.919**__	1.000	-.038	__.093**__	__-.390**__	__-.291**__	__-.128**__	.033	__-.791**__	__-.180**__	__.430**__
WS	.038	-.038	1.000	__.075**__	.043	.053	.026	-.088	.049	.040	-.054
Noise	__-.062*__	__.093**__	__.075**__	1.000	.005	.041	-.002	-.032	-.015	.073	.028
PM_{10}	__.281**__	__-.390**__	.043	.005	1.000	__.927**__	__.279**__				
$PM_{2.5}$	__.187**__	__-.291**__	.053	.041	__.927**__	1.000	__.237**__				
CO	.010	__-.128**__	.026	-.002	__.279**__	__.237**__	1.000				
NO_2	__.096*__	.033	-.088	-.032				1.000	.017		
SO_2	__.791**__	__-.791**__	__.049*__	-.015				.017	1.000		
O_3	__.108*__	__-.180**__	.040	.073						1.000	__-.766**__
CO_2	__-.367**__	__.430**__	-.054	.028						__-.766**__	1.000

Note: *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

Table 7. Statistical summary of spearman correlation coefficient values for road use activities at Mataheko sampling location. Temperature (Temp, °C), relative humidity (RH, %), wind speed (WS, m/s). PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, O_3, CO_2, and Noise during the entire sampling period.

	Temp	RH	WS	Noise	PM_{10}	$Pm_{2.5}$	CO	NO_2	SO_2	O_3	CO_2
Temp	1.000	__-.939**__	__.129**__	__-.107**__	__.284**__	__.175**__	__.123*__	__.452**__	__.565**__	.086	__-.499**__
RH	__-.939**__	1.000	__-.110**__	__.130**__	__-.330**__	__-.187**__	__-.140**__	__-.465**__	__-.592**__	__-.118*__	__.489**__
WS	__.129**__	__-.110**__	1.000	-.010	__.262**__	__.183**__	__.101*__	.066	__.109*__	.065	__-.253**__
Noise	__-.107**__	__.130**__	-.010	1.000	-.025	-.095*	-.018	-.032	-.026	__-.120*__	__.056**__
PM_{10}	__.284**__	__-.330**__	__.262**__	-.025	1.000	__.663**__	__.352**__				
$PM_{2.5}$	__.175**__	__-.187**__	__.183**__	__-.095*__	__.663**__	1.000	__.256**__				
CO	__.123*__	__-.140**__	__.101*__	-.018	__.352**__	__.256**__	1.000				
NO_2	__.452**__	__-.465**__	.066	-.032				1.000	__.387**__		
SO_2	__.565**__	__-.592**__	__.109*__	-.026				__.387**__	1.000		
O_3	.086	__-.118*__	.065	__-.120*__						1.000	__.022**__
CO_2	__-.499**__	__.489**__	__-.253**__	.056						.022	1.000

Note: *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

The construction activities also exhibited slightly similar trends, temperature highly correlated with pollutants except for CO_2, NO_2, and SO_2 even though they also should positive correlations in other activities. RH also negatively correlated with pollutants except for CO_2 ($p < .001$) and noise ($p < .005$). WS also showed a positive correlation between O_3, noise, NO_2, and SO_2 ($p < .005$) (Table 8).

Table 8. Statistical summary of spearman correlation coefficient values for road construction activities A-Q between temperature (Temp, °C), relative humidity (RH, %), wind speed (WS, m/s). PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, O_3, CO_2, and Noise during the entire sampling period.

Activity A

	Temp	RH	WS	Noise	PM_{10}	$PM_{2.5}$	CO
Temp	1.000	-.908**	-.680**	-.225	.025	.468**	.167
RH	-.908**	1.000	.604**	.113	-.079	-.433**	-.103
WS	-.680**	.604**	1.000	.036	-.021	-.415**	-.299
Noise	-.225	.113	.036	1.000	-.011	-.209	-.184
PM_{10}	.025	-.079	-.021	-.011	1.000	.581**	.006
$PM_{2.5}$	.468**	-.433**	-.415**	-.209	.581**	1.000	.423**
CO	.167	-.103	-.299	-.184	.006	.423**	1.000

Activity B

	Temp	RH	WS	Noise	NO_2	SO_2
Temp	1.000	-.906**	-.462**	-.168	.423**	.417**
RH	-.906**	1.000	.410**	.247	-.411**	-.398**
WS	-.462**	.410**	1.000	.057	-.305*	-.196
Noise	-.168	.247	.057	1.000	-.097	-.190
NO_2	.423**	-.411**	-.305*	-.097	1.000	.411**
SO_2	.417**	-.398**	-.196	-.190	.411**	1.000

Activity C

	Temp	RH	WS	Noise	O_3	CO_2
Temp	1.000	-.870**	.375	-.100	.795**	-.603**
RH	-.870**	1.000	-.286	-.176	-.800**	.605**
WS	.375	-.286	1.000	-.204	.524*	-.070
Noise	-.100	-.176	-.204	1.000	.005	.047
O_3	.795**	-.800**	.524*	.005	1.000	-.493*
CO_2	-.603**	.605**	-.070	.047	-.493*	1.000

Activity D

	Temp	RH	WS	Noise	PM_{10}	$PM_{2.5}$	CO
Temp	1.000	-.760**	-.184	-.035	.523**	.495*	.227
RH	-.760**	1.000	.277	-.061	-.640**	-.573**	-.534**
WS	-.184	.277	1.000	-.319	-.080	-.010	-.111
Noise	-.035	-.061	-.319	1.000	-.060	-.054	.113
PM_{10}	.523**	-.640**	-.080	-.060	1.000	.924**	.589**
$PM_{2.5}$	.495*	-.573**	-.010	-.054	.924**	1.000	.459*
CO	.227	-.534**	-.111	.113	.589**	.459*	1.000

Activity E

	Temp	RH	WS	Noise	NO_2	SO_2
Temp	1.000	-.815**	-.211	-.233	.587**	.620**
RH	-.815**	1.000	.142	.095	-.555**	-.537**
WS	-.211	.142	1.000	.156	-.310	-.234
Noise	-.233	.095	.156	1.000	-.019	-.223
NO_2	.587**	-.555**	-.310	-.019	1.000	.444**
SO_2	.620**	-.537**	-.234	-.223	.444**	1.000

Activity F

	Temp	RH	WS	Noise	O_3	CO_2
Temp	1.000	-.886**	-.004	-.148	.066	.234
RH	-.886**	1.000	-.223	.202	-.027	-.355
WS	-.004	-.223	1.000	-.347	-.493**	.180
Noise	-.148	.202	-.347	1.000	.161	-.046
O_3	.066	-.027	-.493**	.161	1.000	.187
CO_2	.234	-.355	.180	-.046	.187	1.000

Activity G

	Temp	RH	WS	Noise	NO_2	SO_2
Temp	1.000	-.488**	-.528**	.262	.209	-.142
RH	-.488**	1.000	.166	-.159	-.445**	.252
WS	-.528**	.166	1.000	-.136	-.091	.149
Noise	.262	-.159	-.136	1.000	.450**	-.025
NO_2	.209	-.445**	-.091	.450**	1.000	-.219
SO_2	-.142	.252	.149	-.025	-.219	1.000

Activity H

	Temp	RH	WS	Noise	O_3	CO_2
Temp	1.000	-.713**	-.243	.047	.194	-.342*
RH	-.713**	1.000	.125	-.304	-.120	.314
WS	-.243	.125	1.000	.139	.421*	-.195
Noise	.047	-.304	.139	1.000	-.480**	.271
O_3	.194	-.120	.421*	-.480**	1.000	-.685**
CO_2	-.342*	.314	-.195	.271	-.685**	1.000

Activity I

	Temp	RH	WS	Noise	PM_{10}	$PM_{2.5}$	CO
Temp	1.000	-.773**	-.383*	.040	.376*	.010	.328
RH	-.773**	1.000	.438*	-.099	-.703**	-.183	-.671**
WS	-.383*	.438*	1.000	.043	-.219	-.163	-.204
Noise	.040	-.099	.043	1.000	-.019	.018	-.028
PM_{10}	.376*	-.703**	-.219	-.019	1.000	.416*	.962**
$PM_{2.5}$	.010	-.183	-.163	.018	.416*	1.000	.350*
CO	.328	-.671**	-.204	-.028	.962**	.350*	1.000

Activity J

	Temp	RH	WS	Noise	PM_{10}	$PM_{2.5}$	CO
Temp	1.000	-.892**	-.024	.049	.477**	.689**	.194
RH	-.892**	1.000	.052	.067	-.490**	-.735**	-.153
WS	-.024	.052	1.000	.287	.004	-.040	-.051
Noise	.049	.067	.287	1.000	-.078	.028	-.020
PM_{10}	.477**	-.490**	.004	-.078	1.000	.793**	.203
$PM_{2.5}$	.689**	-.735**	-.040	.028	.793**	1.000	.289
CO	.194	-.153	-.051	-.020	.203	.289	1.000

Activity K

	Temp	RH	WS	Noise	NO_2	SO_2
Temp	1.000	-.920**	.047	-.603*	-.021	.233
RH	-.920**	1.000	-.068	.540*	.147	-.352
WS	.047	-.068	1.000	.032	-.594*	-.008
Noise	-.603*	.540*	.032	1.000	-.144	-.143
NO_2	-.021	.147	-.594*	-.144	1.000	-.407
SO_2	.233	-.352	-.008	-.143	-.407	1.000

Activity L

	Temp	RH	WS	Noise	NO_2	SO_2
Temp	1.000	-.178	-.361	.144	-.451	-.314
RH	-.178	1.000	.037	.553	-.613*	-.050
WS	-.361	.037	1.000	-.073	.110	-.105
Noise	.144	.553	-.073	1.000	-.648*	.200
NO_2	-.451	-.613*	.110	-.648*	1.000	.470
SO_2	-.314	-.050	-.105	.200	.470	1.000

Activity M

	Temp	RH	WS	Noise	O_3	CO_2
Temp	1	-.471*	-.088	-.218	-.142	-.048
RH	-.471*	1	.193	.188	-.347	-.015
WS	-.088	.193	1	.232	-.219	.098
Noise	-.218	.188	.232	1	-.053	.000
O_3	-.142	-.347	-.219	-.053	1	-.008
CO_2	-.048	-.015	.098	.000	-.008	1

Activity N

	Temp	RH	WS	Noise	NO_2	SO_2
Temp	1.000	-.787**	-.428**	.070	-.528**	-.403*
RH	-.787**	1.000	.524**	.109	.693**	.526**
WS	-.428**	.524**	1.000	.410*	.371*	.353*
Noise	.070	.109	.410*	1.000	.256	.312
NO_2	-.528**	.693**	.371*	.256	1.000	.285
SO_2	-.403*	.526**	.353*	.312	.285	1.000

Activity O

	Temp	RH	WS	Noise	PM_{10}	$PM_{2.5}$	CO
Temp	1	-.879**	-.461*	.079	-.145	-.346	.169
RH	-.879**	1	.484**	-.334	.406*	.575**	-.151
WS	-.461*	.484**	1	-.030	-.064	.132	.044
Noise	.079	-.334	-.030	1	-.452*	-.394*	.021
PM_{10}	-.145	.406*	-.064	-.452*	1	.751**	.283
$PM_{2.5}$	-.346	.575**	.132	-.394*	.751**	1	-.121
CO	.169	-.151	.044	.021	.283	-.121	1

Activity P

	Temp	RH	WS	Noise	O_3	CO_2
Temp	1.000	-.401	-.203	.305	-.225	-.460
RH	-.401	1.000	.156	-.493	.318	.036
WS	-.203	.156	1.000	.237	-.116	.441
Noise	.305	-.493	.237	1.000	-.633**	-.010
O_3	-.225	.318	-.116	-.633**	1.000	.407
CO_2	-.460	.036	.441	-.010	.407	1.000

Activity Q

	Temp	RH	WS	Noise	NO_2	SO_2
Temp	1.000	-.946**	-.116	-.235	.255	.273
RH	-.946**	1.000	.066	.248	-.317	-.287
WS	-.116	.066	1.000	-.301	-.086	-.377
Noise	-.235	.248	-.301	1.000	-.175	.013
NO_2	.255	-.317	-.086	-.175	1.000	.091
SO_2	.273	-.287	-.377	.013	.091	1.000

Note: *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

3.5. *Correlation Between the Traffic Volume and Air Pollutants (Somanya and Mataheko)*

There was a statistically significant, strong positive correlation between traffic volume and PM_{10}, *rs*(2) = .928, *p* < .001. whereas there was no statistically significant correlation between traffic volume and air pollutants at the Mataheko location.

4. Conclusions

The study results confirmed (Somanya) location recorded air pollutants significantly above the WHO and GSA permissible limits. Mataheko also recorded values that exceeded the WHO and GSA limits except for SO_2. Statistically comparing the median of the two locations showed that they were not the same and differed significantly. Also, the sampling day mattered when considering the quantity of pollutants generated. Even though it was expected that the number of cars per hour estimated from the Mataheko location was twice as much as that of the Somanya location, it did not produce twice as many pollutants; instead, traffic volume only showed an association between PM_{10} at the Somanya location.

Similarly, there was a strong association between the meteorological parameters and the air pollutants across the two sampling locations. The pollutants generated from the road construction sampling were also significantly above the WHO and GSA standards. These include PM_{10}, $PM_{2.5}$, NO_2, SO_2, and noise.

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