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Assessment of Air Quality and Noise Levels Around Indoor and Outdoor Welding Workshops In Port Harcourt Nigeria

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Abstract
Background: *Welding involves the heating of metals to suitable temperature which produces coalescence. In the process fumes containing oxides of the metal and particulate matter are emitted into the environment.* ***Materials and Methods:*** *The study was carried out to assess air quality around welding workshops in Port Harcourt and Environs. Digital monitors were used for in situ monitoring of levels of particulate matter ($PM_{2.5}$ and PM_{10}), gaseous pollutants (NO_2, CO and SO_2) and Noise. Nine welding workshops consisting of 5 outdoor and 4 indoor were assessed at 0 meters, 15 – 20 meters and 20 -50 meters (control) from the welding workshops. The monitoring of air quality was done over a period of three months spanning from October 2019 to January 2020.*
Results: *The highest concentrations of air pollutants and noise at indoor welding workshop were 0.13 mg/m^3 ($PM_{2.5}$); 0.37 mg/m^3 (PM_{10}); 0.09 ppm (NO_2); 0.34 ppm (CO); 0.21 ppm (SO_2) and 84.04 dB(A) (noise). At outdoor workshops the highest concentrations of air pollutants and noise were: 0.34 mg/m^3 ($PM_{2.5}$); 0.5 mg/m^3 (PM_{10}); 0.13 ppm (NO_2); 0.37 ppm (CO), 0.52 ppm (SO_2) and 87 dB(A) (Noise). $PM_{2.5}$, PM_{10} and NO_2 were significantly higher ($p<0.1$) at the welding workshop than at the surrounding distance. Pollutant levels at Indoor welding workshops and Outdoor welding workshops did not show any significant difference ($p>0.1$).*
Conclusion: *The study therefore concludes that welding workshops contribute significant amounts of air pollutants and pose health risk to welders and residents alike.*

Key words: *Air Quality, Particulate Matter, Gaseous Pollutants, Noise, Welding Workshops*

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I. Introduction

As the city expands and properties are developed rapidly, the need for metal works is growing at an astronomical rate in Port Harcourt. Welders are in great demand and so are welding workshops springing up across the city. Around Port Harcourt and its environs, welding is extensively applied in construction sites and manufacturing industries like in shipyards, tank farms, bridge building, in oil and gas transmission companies, piping system and petrochemical industries, etc. The American Welding Society defined welding as ―a metal joining process wherein coalescence is produced by heating to suitable temperature with or without the use of filler metal‖ (AWS, 2010). The benefits of welding notwithstanding, the emission of fumes/dust and poisonous gases constitute environmental hazard (Leman, *et. al.*, 2010). Fumes or dust emitted during welding mainly contain oxides of metals which are produced due to the interaction of vaporized metals and oxygen in the air. Thus, chemical hazards as a result of welding can be grouped into particulates (lead, nickel, zinc, iron oxide, copper, cadmium, fluorides, manganese, and chromium) and gases (carbon monoxide, carbon dioxide, oxides of nitrogen, phosgene, oxides of sulphur, ozone and trichloroethylene), (Riccelli, *et.al.*, 2020).

Welding can be done both indoor and outdoor, depending on workplace conditions. An indoor welding is a work environment where welding is done in a confined space, or a closed space like workshops, tanks, vaults, pipelines and any closed area in industries. Indoor working environment is characterized by ‗limited space, entry or exit; poor ventilation and lack of safe breathing air' (Golbabaei and Khadem, 2015). An outdoor working environment is any work done in an open space and is characterized by less restrictions and more ventilation.

Welders are exposed to varying degree of hazards based on the workplace condition. Outdoor workers spend more time in the open and have to contend with unpredictable weather conditions which could go from extreme hot to extreme cold. They are sometimes also exposed to storm, ultraviolet (UV) radiation, bugs and wild animals and even strong winds (Golbabaei and Khadem, 2015).

However outdoor workers are faced with less pollution due to fumes and gases arising from the welding process, as the concentration of these pollutants are likely more dispersed in outdoor working conditions. Whereas workers in indoor welding workplaces which are characterized by limited space are more exposed to fire outbreaks, explosion and exposure to harzadous air contaminants (Golbabaei and Khadem, 2015).

There are a number of health risks welders are exposed to, but as welding has left the confines of the industry and is now carried out in residential areas, the health risk may have evolved beyond being the concern of welders alone but could be a source of worry for residents alike (Mgonja, 2017; Emmet et al.,1981; Kadinda, 2007). The phenomenon of air pollution involves the generation of pollutants and the subsequent release into the atmosphere. World Health Assembly, WHA (2018) reported that more than 6 million deaths annually are caused by air pollution. Also, some researchers have linked welding to certain health problems like breathing difficulty, anemia, cancer, emphysema, headache, chronic bronchitis, pulmonary edema, metal fume fever and irritation of the mucous membranes and narrows branches of the respiratory organs (Sjogren et.al., 1996; Ediagbonya, *et. al.*, 2016). This is due to certain pollutants that enter the atmosphere as a result of welding activities. Welders are the most affected by this environmental hazard; however others who work or live close to a welding site can be affected as well as air current carry the pollutants through the surrounding atmosphere.

II. Materials And Method

Study Area

Port Harcourt with coordinates $4^{0}49^{/}27^{//}$N and $7^{0}2^{/}1^{//}$E located along the Bonny River is the capital city of Rivers State and is the hub of oil and gas industry in Nigeria. Its metropolis stretches from Omagwa International airport and also from the Refinery at Alesa Eleme to Choba Community (Akinfolarin, *et. al*., 2017). Port Harcourt has a tropical wet climate with long rainy season and short dry season. There are lots of industrial activities around the city which include construction work requiring a lot of welding work.

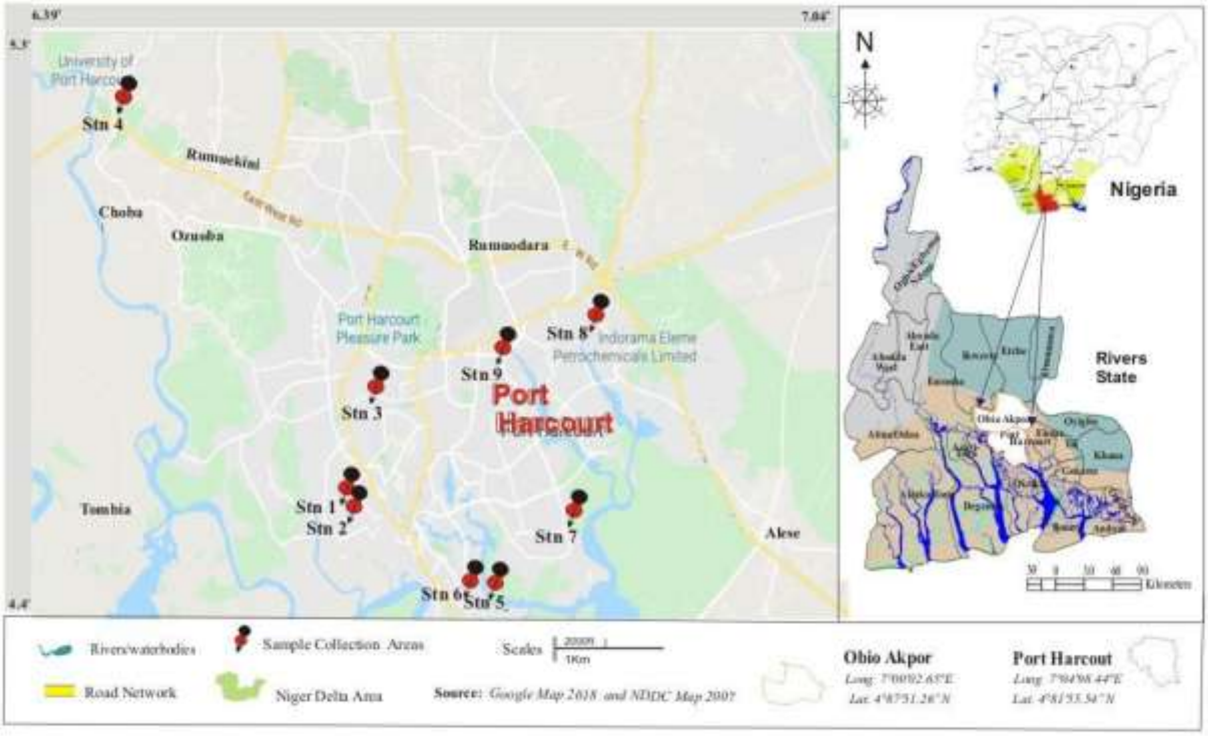

Fig 1: Map Showing the Study Area

Table 1: Identification of Sampling Locations

STNS	LOCATION	CODE	LOCATION TYPE	GPS
1	Rivers State University Engineering Workshop	RSUW	Indoor	N 04°47'37" E 006°58'47.0"
2	Rivers State University Estate Department	RSUE	Indoor	N 04°47'52.6" E 006°58'59.5"
3	Cherubim Road Mile 3	CHER	Outdoor	N04°48'22.6" E006°59'23.7"

4	University of Port Harcourt Engineering Workshop	UPHE	Indoor	N 04°53'37.9" E 006°54'25.1
5	Victoria/Rebisi Street, Port Harcourt Town	VICT	Outdoor	N 04°45'40" E 007°1'51"
6	Tourist Beach Road, Port Harcourt Town	TOUR	Indoor	N 04°45'27.9" E 007°02'24.7"
7	Okuru-ama Road	OKUR	Outdoor	N 04°47'22.4" E 007°03'16.8"
8	Trans Woji Road, Elelenwo	ELEL	Outdoor	N 04°49'45.6" E 007°04'14.3"
9	Trans Amadi Industrial Layout, Rumuobiakani	TAMA	Outdoor	N 04°49'47.5" E 007°02'05.9"

Measurements were made at nine locations (Table 1). The Locations were characterized based on whether they are welding workshops confined in a building (indoor) or they are in an open space without walls (outdoor). Out of the nine sampling stations there were four indoor welding workshops (stations 1, 2, 4 and 6) and five outdoor welding workshops (stations 3,5,7,8 and 9).

Sample Collection/Sampling Frequency

Digital aeroqual gas monitors were used to monitor air pollutants twice daily, during work hours and at the close of work. The frequency of measurement was once every month for three months.

III. Results And Discussion

Table 2: Mean Levels of Air Pollutants, Noise and Meteorological Parameters Measured at the Study Sites

Workshops	Sampling Points	Suspended Particulates (mg/m³)		Gases (ppm)			Noise dB(A)	Temp (°C)	RH (%)	Wind Speed (m/s)	Wind Direction
		$PM_{2.5}$	PM_{10}	NO_2	SO_2	CO					
RSUW (Indoor)	0	0.05±0.03	0.24±0.16	0.04±0.01	BDL	0.01±0.01	61.30±12.45	30.00±.0.14	67.15±2.62	0.55±0.07	SW
	1	0.03±0.02	0.11±0.05	0.02±0.00	BDL	0.04±0.03	56.95±12.23	29.35±2.47	62.25±5.73	1.49±0.86	SW
	2	0.02±0.01	0.11±0.07	0.02±0.01	BDL	0.12±0.04	52.70±0.71	31.35±1.34	60.38±2.16	1.625±1.10	SW
RSUE (Indoor)	0	0.03±0.00	0.20±0.03	0.04±0.01	BDL	BDL	60.63±17.49	31.35±0.07	62.96±7.56	0.85±0.35	SW
	1	0.02±0.00	0.12±0.03	0.01±0.01	0.02±0.25	0.01±0.01	57.24±10.13	34.40±2.40	61.51±4.09	2.10±0.67	SW
	2	0.01±0.01	0.09±0.03	0.011±0.01	BDL	0.06±0.03	52.29±9.91	33.20±2.26	63.02±0.74	2.20±0.99	SW
CHER (Outdoor)	0	0.04±0.01	0.13±0.00	0.13±0.03	0.52±0.01	0.20±0.00	74.50±11.46	36.40±0.28	59.70±0.57	1.02±0.47	SW
	1	0.08±0.02	0.50±0.01	0.09±0.01	0.35±0.00	0.088±0.02	77.70±3.53	36.30±0.14	60.15±0.07	1.45±0.50	SW
	2	0.09±0.00	0.46±0.02	0.04±0.01	0.20±0.03	0.13±0.15	76.48±10.72	35.90±0.00	58.13±0.80	1.48±0.18	SW
UPHE (Indoor)	0	0.09±0.02	0.37±0.07	0.09±0.05	0.21±0.11	0.01±0.02	84.04±6.55	30.90±3.54	66.38±3.37	0.89±0.12	SW
	1	0.07±0.03	0.12±0.06	0.04±0.00	0.12±0.03	0.02±0.01	70.28±14.54	28.76±1.61	67.47±5.56	1.36±0.35	SW
	2	0.02±0.03	0.06±0.08	0.02±0.01	0.16±0.01	0.01±0.00	64.09±3.66	27.52±0.45	64.55±6.01	1.40±0.57	SW
VICT (Outdoor)	0	0.03±0.00	0.04±0.01	0.06±0.00	BDL	0.01±0.00	83.00±8.49	31.90±1.84	55.70±3.25	1.60±0.71	SW
	1	0.01±0.00	0.02±0.01	0.06±0.01	BDL	0.17±0.22	61.00±1.41	33.35±0.78	58.40±0.14	1.63±0.50	SW
	2	0.01±0.00	0.02±0.00	0.04±0.00	BDL	0.02±0.01	61.15±1.63	33.85±0.35	52.90±0.99	1.57±0.30	SW
TOUR (Indoor)	0	0.13±0.04	0.17±0.04	0.07±0.00	BDL	0.29±0.01	77.65±11.95	35.25±0.35	53.95±0.21	1.20±0.14	SW
	1	0.06±0.00	0.18±0.04	0.03±0.00	BDL	0.34±0.01	70.50±0.71	35.95±0.35	52.85±0.21	1.75±0.50	SW
	2	0.06±0.04	0.17±0.04	0.02±0.00	BDL	0.25±0.01	61.15±4.03	35.75±0.35	52.75±0.21	1.36±0.20	SW
OKUR (Outdoor)	0	0.34±0.04	0.25±0.00	0.07±0.00	BDL	0.28±0.01	79.45±0.92	33.65±0.78	56.15±0.21	1.40±0.14	SW
	1	0.15±0.04	0.09±0.02	0.06±0.00	BDL	0.27±0.01	77.30±2.83	33.45±2.76	54.05±0.07	1.45±0.21	SW
	2	0.11±0.04	0.07±0.00	0.06±0.00	BDL	0.21±0.01	56.65±1.48	34.40±1.41	50.85±0.35	1.20±0.00	SW
TAMA (Outdoor)	0	0.05±0.06	0.04±0.03	0.09±0.01	BDL	0.37±0.12	68.50±12.02	32.25±3.32	55.75±1.06	3.40±1.56	SW
	1	0.02±0.02	0.02±0.00	0.07±0.02	BDL	0.28±0.00	67.00±8.49	32.05±3.46	52.80±2.12	3.70±1.9	SW
	2	0.01±0.00	0.03±0.00	0.05±0.01	BDL	0.24±0.02	58.50±2.12	32.65±3.61	51.25±1.06	3.73±1.52	SW
ELEL (Outdoor)	0	0.11±0.00	0.13±0.00	0.08±0.00	BDL	0.31±0.04	87.00±1.41	31.00±2.83	62.35±1.20	1.50±0.14	SW
	1	0.08±0.00	0.11±0.01	0.05±0.00	BDL	0.2±``0.03	84.70±4.67	32.80±2.55	60.05±1.06	1.95±0.64	SW
	2	0.06±0.00	0.10±0.01	0.05±0.00	BDL	0.18±0.08	77.55±2.05	33.20±1.70	59.95±0.21	1.80±0.42	SW

BDL = Below Detection Limit

The levels of $PM_{2.5}$ were shown in table 2 and in Figs 2 and 3 for indoor and outdoor welding workshops respectively. At indoor welding workshops, the values ranged from 0.03 mg/m^3 at RSUE to 0.13 mg/m^3 at TOUR with mean of 0.075±0.04 mg/m^3 at point 0; 0.02 mg/m^3 at RSUE to 0.07 mg/m^3 at UPHE with mean of 0.045±0.02 mg/m^3 at point 1 and 0.01 mg/m^3 at RSUE to 0.06 mg/m^3 at TOUR with mean of 0.028±0.02 mg/m^3 at point 2. The trend of mean concentration of $PM_{2.5}$ across the three sampling points at indoor workshops are in the decreasing order of Point 0 > Point 1 > Point 2 thus indicating that high $PM_{2.5}$ level was due to the welding activity. The observed trend of decreasing concentration of $PM_{2.5}$ away from the welding workshop could be due to wind action which dispersed the particulates. Point 0 has significantly ($p < 0.1$) higher levels of $PM_{2.5}$ than those recorded at points 1 and point 2.

At the outdoor welding workshops the levels of $PM_{2.5}$ ranged from 0.03 mg/m^3 at VICT – 0.34 mg/m^3 at OKUR with mean of 0.114±0.13 mg/m^3 at point 0; 0.01 mg/m^3 at VICT – 0.15 mg/m^3 at OKUR with mean of 0.068±0.06 mg/m^3 at point 1 and 0.01 mg/m ^{3} at VICT – 0.11 mg/m^3 at OKUR with mean of 0.056±0.05 mg/m^3 at point 2. The concentrations of $PM_{2.5}$ at outdoor workshops followed similar trend pattern as the indoor workshops with Point 0 > Point 1 > Point 2. However, one of the outdoor workshops, CHER followed a reverse trend of Point 2 > Point 1> Point 0. The levels observed at CHER could have been influenced by the presence of other artisanal activities including a saw-mill and vehicular activities on a busy road which contributed to the particulate matter at this location. However, the results showed no significant difference ($p > 0.1$) in the concentrations of outdoor $PM_{2.5}$ between point 0 and point 1 and between point 0 and point 2.

The concentrations of $PM_{2.5}$ in outdoor welding workshops were generally higher than the concentrations in indoor welding workshops (Fig 4). The levels of $PM_{2.5}$ at the welding workshops were ten times higher than the levels of 0.001 – 0.034 mg/m^3 reported by Gobo, *et al.* (2012) in their assessment of air quality in Okrika, Rivers State. The high level of fine particulate matter at the welding workshops was caused by the heating of metals above their melting point during coalescence resulting in the vapourisation and condensation of metals (IARC, 2018, AWS, 2010). This resulted in higher levels of $PM_{2.5}$ above ambient levels studied by Gobo *et. al.* (2012). However, <2.5 µm particulate matter concentrations reported by Akinfolarin, *et. al.* (2017) in their assessment of particulate matter-based air quality in Port Harcourt were related to those observed in this study. The concentrations of $PM_{2.5}$ in this study were compared with permissible limits of 0.025 mg/m^3 (25 µg/m^3), 0.035 mg/m^3 (35 µg/m^3) and 0.15 mg/m^3 respectively set by WHO (2018), USEPA (2020) and FEPA (2003). The concentrations of $PM_{2.5}$ in most of the stations were found to exceed the limits recommended by WHO (2018) and USEPA (2020) except at RSUW (point 2), RSUE (point 1 and 2), UPHE (point 2), VICT (point 1 and 2) and ELEL (point 1 and 2) which were below the recommended limits. In addition to these RSUW (point 1), RSUE (point 0) and VICT (point 0) were below USEPA (2020) limits. However, the concentrations of $PM_{2.5}$ in all the sampling stations were below the recommended limits in FEPA (2003) except OKUR (point 1 and 2) which exceeded the recommended limits.

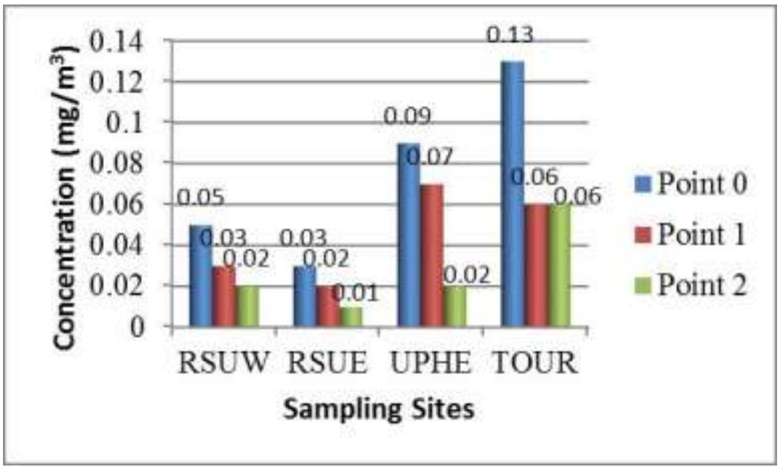

Fig 2: Variations in Indoor Levels of $PM_{2.5}$ with Sampling Sites

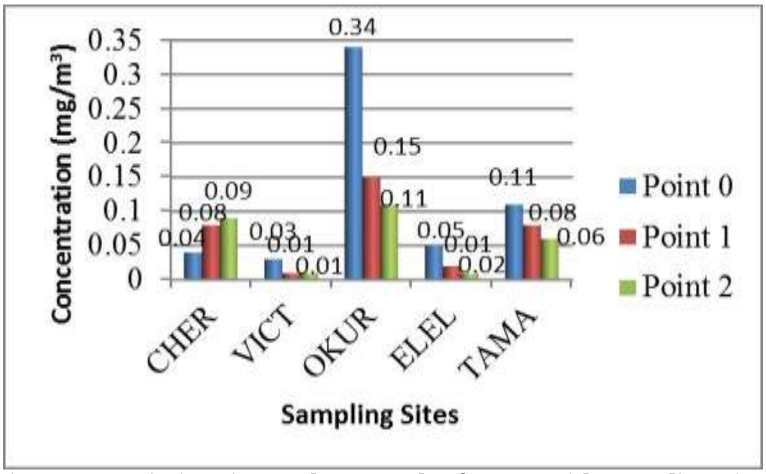

Figure 3: Variations in Outdoor Levels of $PM_{2.5}$ with Sampling Sites

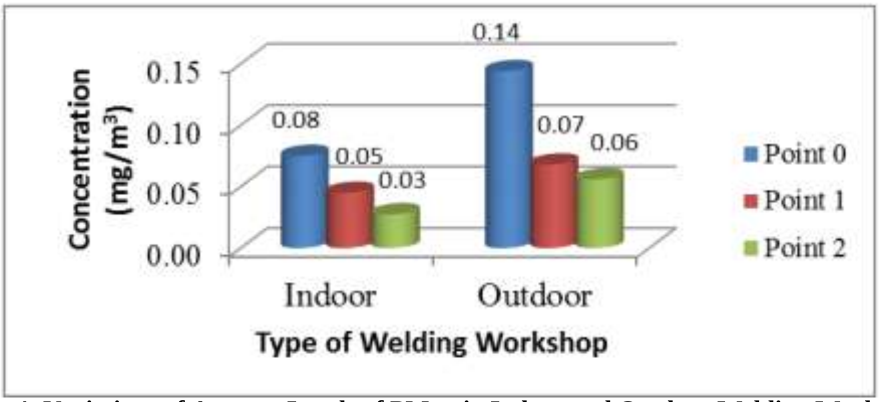

Figure 4: Variations of Average Levels of $PM_{2.5}$ in Indoor and Outdoor Welding Workshops

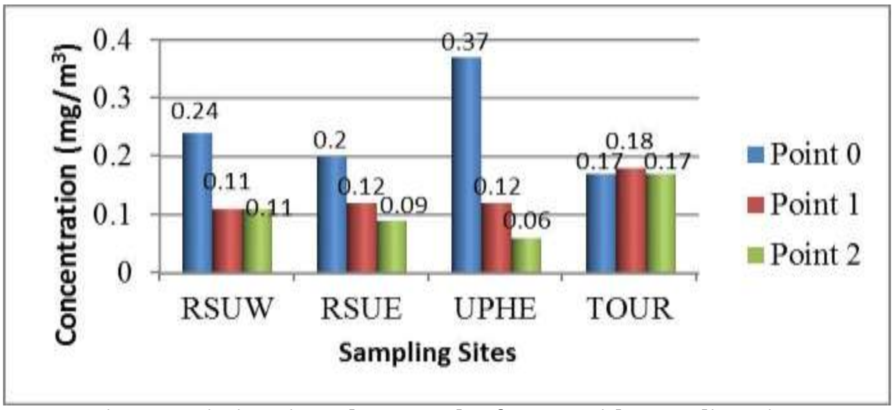

Fig 5: Variations in Indoor Levels of PM_{10} with Sampling Sites

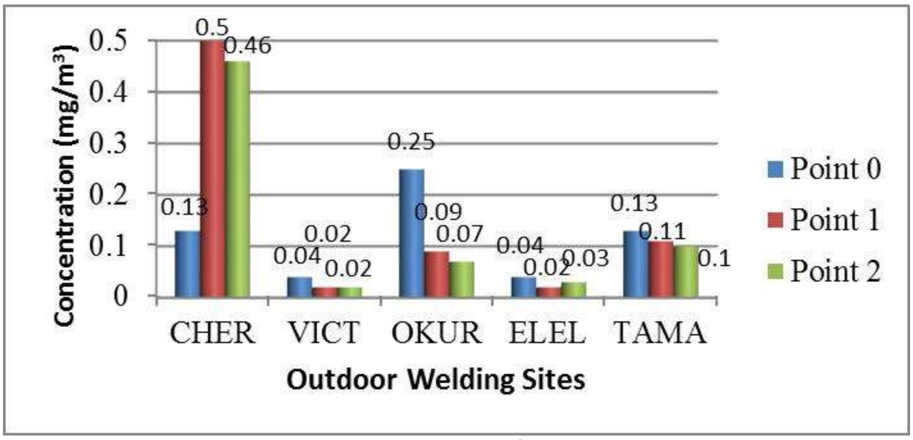

Fig 6: Variations in Outdoor Levels of PM_{10} with Sampling Sites

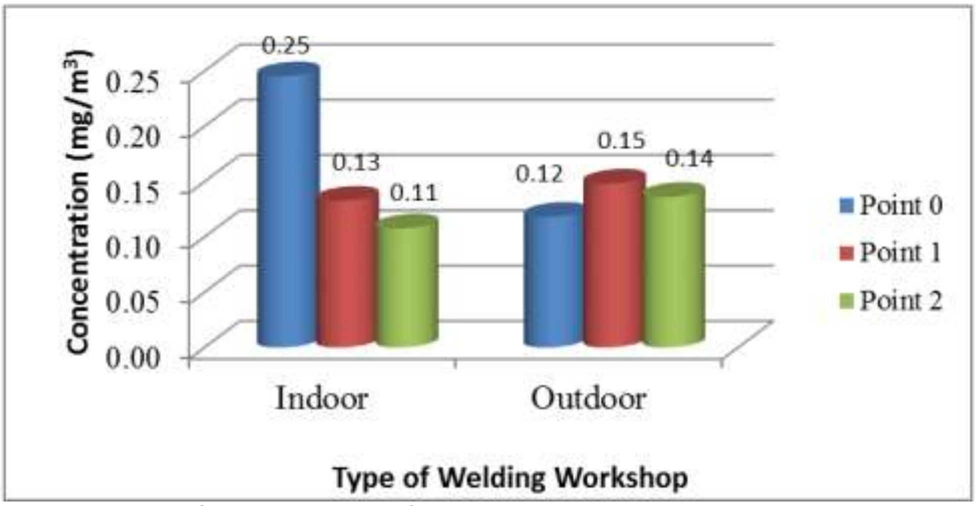

Fig 7: Variation of Average Levels of PM_{10} in Indoor and Outdoor Welding Workshop

The levels of PM_{10} were shown in table 2 and Figs 5 and 6 for indoor and outdoor welding workshops respectively. At indoor welding workshops, the levels ranged from 0.17 mg/m^3 at TOUR to 0.37 mg/m^3 at UPHE with mean of 0.25±0.09 mg/m^3 at point 0; 0.11 mg/m ^{3} at RSUW to 0.18 mg/m^3 at TOUR with mean of 0.13±0.03 mg/m^3 at point 1 and 0.06 mg/m^3 at UPHE to 0.17 mg/m^3 at TOUR with mean of 0.11±0.05 mg/m ^{3} at point 2. The concentrations of PM_{10} were in the decreasing order of point 0 > point 1> point 2 at almost all the indoor welding workshops except at Tourist Beach which did not follow any particular order. The PM_{10} levels showed significant difference ($p < 0.1$) between point 0 and point 1 and between point 0 and point 2.

At the outdoor welding workshops the PM_{10} levels ranged from 0.04 mg/m^3 at VICT and ELEL to 0.25 mg/m^3 at OKUR with mean of 0.118±0.09 mg/m^3 at point 0; 0.02 mg/m^3 at VICT and ELEL to 0.5 mg/m^3 at CHER with mean of 0.148±0.20 mg/m^3 at point 1; 0.02 mg/m^3 at VICT to 0.46 mg/m^3 at CHER with mean of 0.136±0.18 mg/m^3 at point 2. The PM_{10} levels at the outdoor workshops showed no particular trend and no significant difference across point 0, point 1 and point 2. These observations indicate that high PM_{10} levels at indoor workshops are attributable to fumes released during the welding process, while at outdoor workshops contributions from other anthropogenic sources are of greater significance.

Furthermore, PM_{10} levels at the study locations are similar to those reported from other studies within the study area. In Edokpa & Ede (2019), PM_{10} concentrations in and around urban settlements in Port Harcourt ranged from 275 µg/m^3 (0.275 mg/m^3) – 1290 µg/m^3 (1.29 mg/m^3). In Weli & Ayoade (2014) ambient air quality values for PM_{10} in Port Harcourt ranged from 70 µg/m^3 (0.07 mg/m^3) – 494 µg/m^3 (0.49 mg/m^3). These levels are within the range of this study, thereby suggesting that welding workshops do not significantly alter the levels of coarse particulates. This is in agreement with Antonini (2014) who reported that the primary particles formed during welding have been observed to be in the ultrafine size range. This is also supported by IARC (2018) which stated that ―welding fumes consist of predominantly fine solid particles with an aerodynamic diameter of less than 1 µm, and are a complex mixture of particles from the wire or electrode, base metal, or any coatings on the base metal‖. The recommended limit of PM_{10} by WHO (2006) and EU (2008) is 50 µg/m^3 (0.05 mg/m^3), while the limit set by USEPA (2020) and NESREA (2014) is 150 µg/m ^{3} (0.15 mg/m^3). The concentrations of PM_{10} in the welding workshop were above the limits recommended by WHO (2006) and EU (2008) except ELEL and VICT which were below permissible limits. The concentration of PM_{10} observed at CHER, TOUR, UPHE and RSUW were above the limits recommended by USEPA (2020) and NESREA (2014) while others were below the recommended limits.

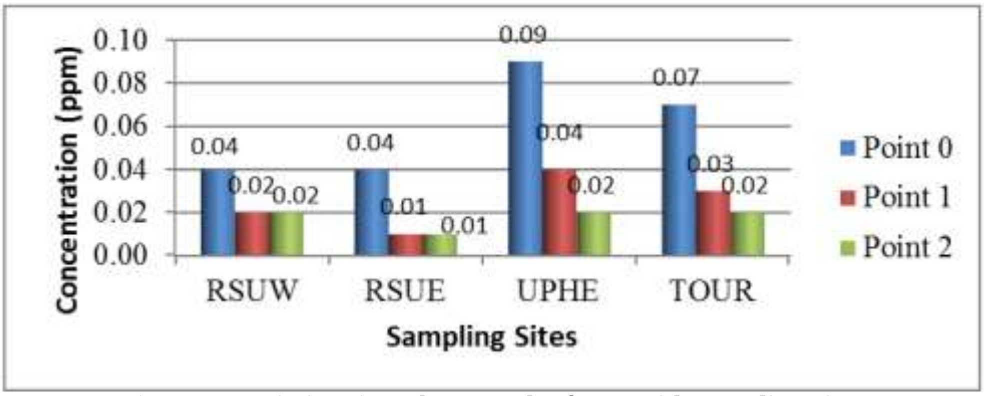

Figure 8: Variations in Indoor Levels of NO_2 with Sampling Sites

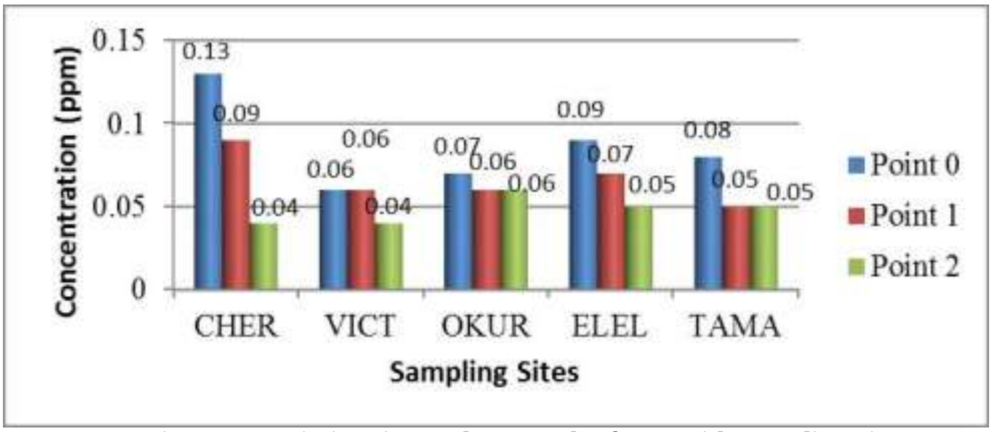

Figure 9: Variations in Outdoor Levels of NO_2 with Sampling Sites

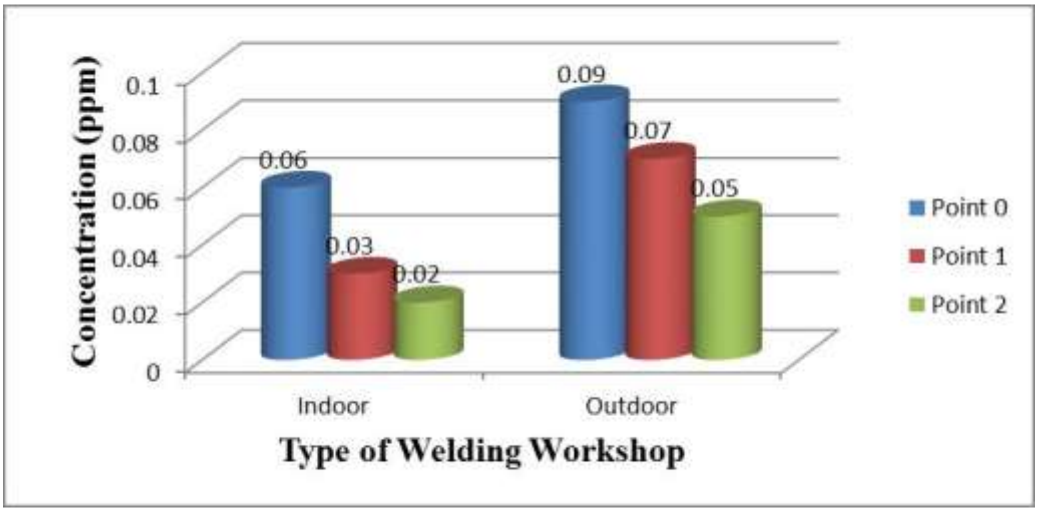

Figure 10: Variations of Average Levels of NO_2 Indoor and Outdoor Welding Workshop

The concentrations of NO_2 are shown in Figs 8, 9 and 10. At indoor welding workshops they varied from 0.04 ppm at RSUW and RSUE to 0.09 ppm at UPHE with mean of 0.06±0.02 ppm at point 0; 0.01 ppm at RSUE to 0.04 ppm at UPHE with mean of 0.025±0.01 ppm at point 1; 0.01 ppm at RSUE to 0.02 ppm at TOUR, UPHE and RSUW with mean of 0.018±0.01 ppm at point 2. The trend of mean concentrations of NO_2 across the three sampling points at indoor workshops are in the decreasing order of Point 0 > Point 1 > Point 2. There was significant difference ($p<0.1$) in the concentration of NO_2 between point 0 and point 1 as well as between point 0 and point 2. There was however no significant difference ($p>0.1$) in the concentration of NO_2 between point 1 and point 2.

At outdoor welding workshops the levels of NO_2 ranged from 0.06 ppm at VICT to 0.13 ppm at CHER with mean of 0.086±0.03 ppm at point 0; 0.05 ppm at TAMA to 0.09 ppm at CHER with mean of 0.066±0.02 ppm at point 1 and 0.04 ppm at CHER and VICT to 0.06 ppm at OKUR with mean of 0.048±0.01 ppm at point 2. The concentrations of NO_2 at outdoor workshops followed the trend of Point 0 > Point 1 > Point 2. At outdoor welding workshops there was significant difference ($p < 0.1$) of concentration of NO_2 between point 0 and point 1 and between point 0 and point 2 as well as between point 1 and point 2.

The high levels of NO_2 are a result of the oxidation of atmospheric nitrogen which occurs under very high temperature during the welding process, (Schoonover *et al.*, 2011). This may have contributed to the higher concentrations of NO_2 recorded at point 0 (in the welding workshop) compared to point 1 and point 2. The NO_2 levels were generally higher at outdoor welding workshops than indoor workshops. However the levels of NO_2 at both indoor and outdoor workshops fall within the limits 200 μg/m^3 (0.106 ppm), 100 ppb (0.1 ppm) and 200 μg/m^3 (0.106 ppm) respectively recommended by WHO (2018), USEPA (2020) and EEA (2008). Furthermore, the concentrations of NO_2 at UPHE (point 0), TOUR (point 0), CHER (point 0 and 1), OKUR (point 0), ELEL (point 0 and 1) and TAMA (point 0) exceeded NESREA recommended limit of 120μg/m^3 (0.064 ppm) (NESREA, 2014).

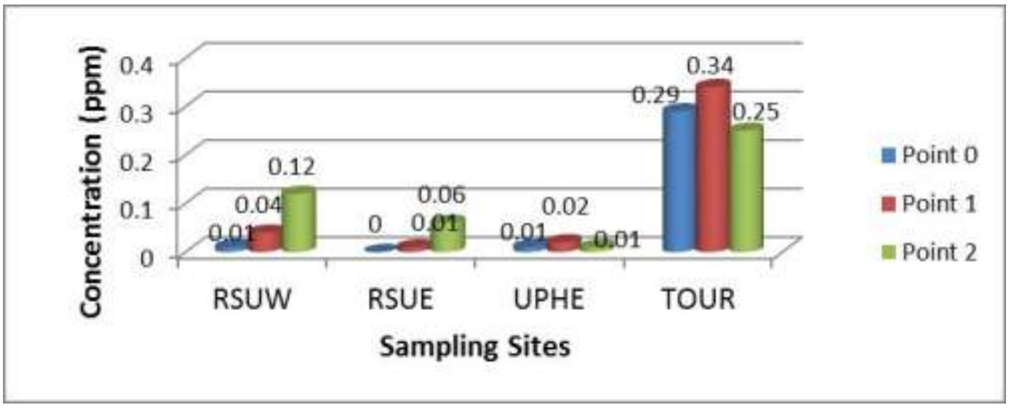

Figure 11: Variations in Indoor Levels of CO with Sampling Sites

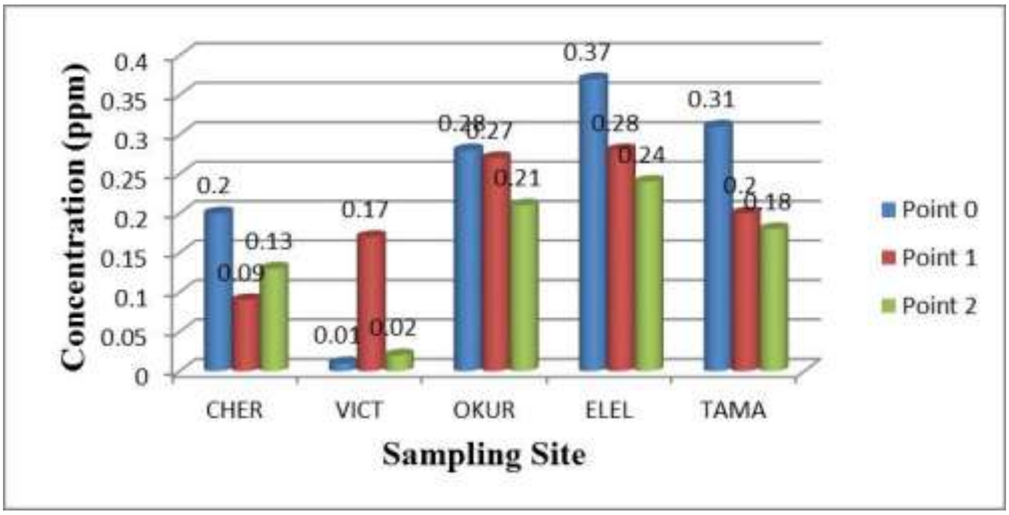

Figure 12: Variations in Outdoor Levels of CO with Sampling Sites

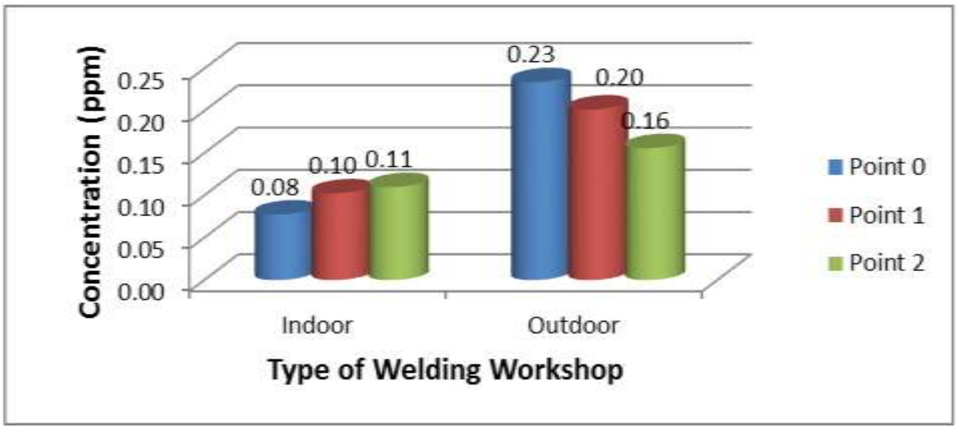

Figure 13: Variations in Average Levels of CO at Indoor and Outdoor Workshops

CO levels at indoor welding workshops varied from 0.00 ppm at RSUE to 0.29 ppm at TOUR with mean of 0.078±0.14 ppm at point 0; 0.01 ppm at RSUE to 0.34 ppm at TOUR with mean of 0.10±0.16 ppm at point 1; 0.01 ppm at UPHE to 0.25 ppm at TOUR with mean of 0.11±0.10 ppm at point 2. The mean concentrations of CO across the three sampling points at indoor workshops were in the increasing order of Point 0 < Point 1 < Point 2.

At outdoor welding workshops the levels of CO ranged from 0.01 ppm at VICT to 0.37 ppm at ELEL with mean of 0.234±0.14 ppm at point 0; 0.09 ppm at CHER – 0.28 ppm at ELEL with mean of 0.20±0.08 ppm at point 1 and 0.02 ppm at VICT – 0.24 ppm at ELEL with mean of 0.156±0.09 ppm at point 2. The concentration of CO at outdoor workshops followed the trend of Point 0 > Point 1 > Point 2 and were higher than those recorded in indoor workshops. However, for both indoor and outdoor workshops there was no significant difference ($p>0.1$) in the concentrations of CO between point 1, point 2 and point 3.

Levels of CO at outdoor welding workshops were generally higher than the levels at indoor welding workshops. The CO concentrations from this study were lower compared to 11.06 mg/m^3 (9.65 ppm) mean level reported by Chukwu *et. al.* (2018) in their study of air quality in welding workshops in Port Harcourt. They were however within the range of 0.1 ppm – 4.3 ppm ambient air quality (during rainy season) reported by Gobo *et al.* (2012). The concentrations of Carbon monoxide recorded at all the welding workshops were below the recommended limits of 35 ppm by USEPA (2020) and 10 mg/m^3 (8.73 ppm) by WHO (2018) and NESREA (2014). The most common sources of CO emission in urban areas are motor vehicle exhaust which accounts for about 70% of air pollution (Topacoglu, *et al*., 2014). Most of the welding workshops were not located at busy road intersections; this may have resulted in the low levels of CO detected at the welding workshops.

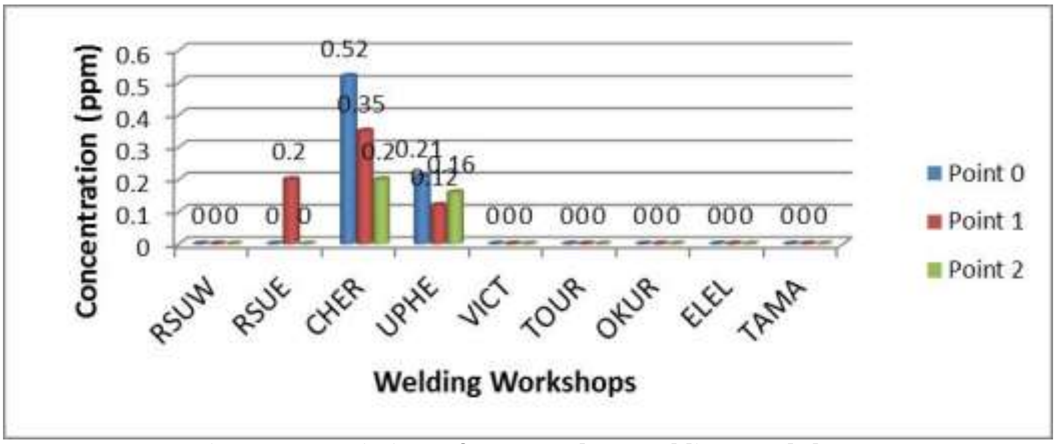

Figure 14: Variations of SO_2 Levels at Welding Workshops

SO_2 levels ranged from 0.12 ppm at UPHE (point 1) to 0.52 ppm at CHER (point 0). SO2 was however below detection limit in RSUW, VICT, TOUR, OKUR, ELEL and TAMA. Welding performed on materials contaminated with sulphur may release sulphur fumes (Government of Alberta, 2009). The very low levels of SO_2 at the welding workshops may be due to low sulphur content of the materials used for welding. However, at all the stations where SO_2 was detected, the levels were above the recommended limits of 75 ppb (0.075 ppm), 20 µg/m^3 (0.008 ppm), 125 µg/m^3 (0.048 ppm) and 0.13 ppm 1 hour mean respectively by USEPA (2020), WHO (2018), EEA (2008) and NESREA (2014). The high SO_2 levels recorded at some welding workshops could be attributed to other anthropogenic activities like exhaust fumes from motor vehicles and power generators.

Table 3: Summary of Inferential Statistics Result of Emission Concentration Differentials from Welding Workshops

Variable		Variable Type	t-Test: Two-Sample Assuming Unequal Variances						
			Mean		tStat	P(T≤t) one-tail	tCritical one-tail	P(T≤t) two-tail	tCritical two-tail
			Variable1	Variable2					
$PM_{2.5}$	Pt0/Pt1	Indoor	0.070	0.044	1.947	0.073*	2.353	0.147	3.184
	Pt0/Pt2	Indoor	0.070	0.027	3.166	0.025*	2.353	0.050*	3.184
	Pt1/Pt2	Indoor	0.044	0.027	1.516	0.113	2.353	0.227	3.184
	Pt0/Pt1	Outdoor	0.114	0.069	1.211	0.146	2.132	0.293	2.776
	Pt0/Pt2	Outdoor	0.114	0.055	1.314	0.130	2.132	0.259	2.776
	Pt1/Pt2	Outdoor	0.069	0.055	1.765	0.076*	2.132	0.152	2.776
PM_{10}	Pt0/Pt1	Indoor	0.245	0.131	2.092	0.037*	2.132	0.073*	2.776
	Pt0/Pt2	Indoor	0.245	0.108	2.758	0.025*	2.131	0.050*	2.776
	Pt1/Pt2	Indoor	0.131	0.108	0.816	0.226	2.015	0.452	2.571
	Pt0/Pt1	Outdoor	0.119	0.148	-0.301	0.388	2.015	0.775	2.571
	Pt0/Pt2	Outdoor	0.119	0.133	-0.156	0.440	1.943	0.881	2.447
	Pt1/Pt2	Outdoor	0.148	0.133	0.126	0.451	1.860	0.903	2.306
NO_2	Pt0/Pt1	Indoor	0.060	0.023	2.783	0.025*	2.132	0.050*	2.776
	Pt0/Pt2	Indoor	0.060	0.017	3.657	0.018*	2.353	0.035*	3.184
	Pt1/Pt2	Indoor	0.023	0.017	1.078	0.171	2.132	0.342	2.776
	Pt0/Pt1	Outdoor	0.086	0.065	1.518	0.090*	1.943	0.180	2.447
	Pt0/Pt2	Outdoor	0.086	0.049	2.862	0.023*	2.132	0.046*	2.776
	Pt1/Pt2	Outdoor	0.065	0.049	2.353	0.028*	1.943	0.057*	2.447
CO	Pt0/Pt1	Indoor	0.078	0.102	-0.231	0.412	1.943	0.825	2.447
	Pt0/Pt2	Indoor	0.078	0.110	-0.371	0.363	2.015	0.726	2.571
	Pt1/Pt2	Indoor	0.102	0.110	-0.082	0.469	2.015	0.938	2.571
	Pt0/Pt1	Outdoor	0.232	0.200	0.456	0.332	1.943	0.665	2.447
	Pt0/Pt2	Outdoor	0.235	0.154	1.082	0.158	1.895	0.315	2.365
	Pt1/Pt2	Outdoor	0.200	0.154	0.882	0.202	1.860	0.404	2.306

pt0, pt1 and pt2 indicate the sampling distance relative to the source point
** result is significant at 0.1 level*

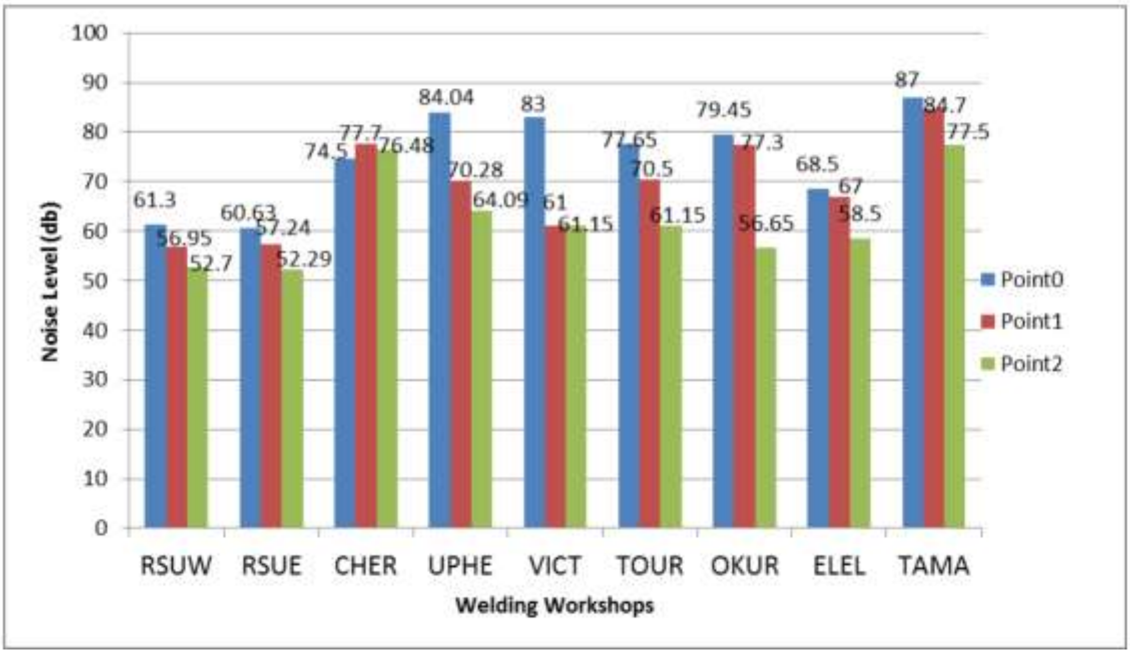

Figure 15: Variations in Noise Levels at Different Welding Workshops

The highest mean noise levels of 87.00±1.41 dB(A) at point 0; 84.7±4.67 dB(A) at point 1 and 77.55±2.05 dB(A) at point 2 were all obtained at ELEL. The noise levels at all the welding workshops except CHER and VICT generally followed the descending order point 0 > point 1 > point 2 at both the outdoor and indoor welding workshops. The high noise levels at the welding stations could be attributed to the popping or crackling noises during welding. The results agree with Gobo *et. al.* (2012) in which the highest mean level of noise was reported to be 83.8 dB(A). The highest noise level observed in the study area was below the OSHA (2013) permissible exposure limit (PEL) of 90 dB(A) for all workers for an 8-hour working day and therefore do not portend serious concerns for human health.

IV. Conclusion

The results of this study have shown that welding workshops contribute significant amount of pollutants to the environment. The levels of air pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}) and NO_2 were found to exceed permissible limits at the welding sites and thereby pose significant concern for both environment and human health. CO_2 and SO_2 were found in small amounts at welding workshops and therefore are not a source of concern. Also, welding workshops are sources of noise pollution in the environment. Regulatory agencies should therefore ensure that welding work areas are restricted to industrial corridors, while adequate personal protective equipment such as nose masks, eye goggles and coveralls should be worn by welders.

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