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Ambient air pollution monitoring and health studies using low-cost Internet-of-things (IoT) monitor within KNUST Community

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Abstract

Urban environments with high industrialization are infested with hazardous chemicals and airborne pollutants. These pollutants CO, O_3, SO_2, NO_2, and PM can have devastating effects on human health, causing both acute and chronic diseases such as respiratory infections, lung cancer, and heart disease. Air pollution monitoring is vital to warn citizens of the health risks associated with exposure to high concentrations of these criteria pollutants. This study designed a low-cost IoT monitor to measure concentration levels of criteria pollutants emitted from transportation sources within Kwame Nkrumah University of Science and Technology environs. Three monitoring sites, KNUST Tech junction, Ayeduase gate junction and KNUST campus junction, were identified as the locations within the proximity of the university for the deployment of the monitor. Hourly and mean daily CO, NO_2, O_3 and SO_2 concentrations at each of the three sites were measured for a week using the IoT monitor, when students were in school and when students were on vacation. The average daily CO, NO_2 and O_3 concentrations measured at the selected locations when school was in session and during vacation were presented on histogram. The mean weekly concentrations of CO, NO_2 and O_3 were also estimated as 13.2ppm, 0.277ppm and 0.106ppb respectively at KNUST Tech junction; 10.1ppm, 0.254ppm and 0.110ppb respectively at Ayeduase gate junction; and 8.0ppm, 0.415ppm and 0.100ppb respectively at the KNUST campus junction when school was in session. The results show that the concentrations of all the pollutants were higher and exceeded the EPA standards except for CO at KNUST Campus junction monitoring site. These high levels of emissions are an indication of a health concern for the students at the university and university authorities can device means of curbing it.

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Keywords: IoT monitor; criteria pollutants; health impact; emission standards; KNUST campus junction.

1. Introduction

Air pollution possess a treat to human health. As our society evolves and more sources of pollution are present in the environment, the impact of air pollution becomes increasingly prominent. This is especially true in densely populated areas, mostly cities around the world, that offer a wide range of infrastructure such as public transportation, industries, and other urban facilities [1-5]. The World Health Organization (WHO) estimates that worldwide, around seven million people die from the effects of air pollution every year. Air pollution is indeed responsible for causing heart disease, strokes, lung cancer, asthma, and chronic respiratory diseases [6,7,8]. According to the WHO, 9 out of 10 people breathe air that exceeds WHO's recommendations pertaining to the levels of pollutants in the air and its relationship with the healthy foods [9-14].

Ambient carbon monoxide (CO) levels have risen, during times of high automobile volumes (Tze-meng Chen et al, 2007). Since the introduction of catalytic converters in motor vehicles, carbon monoxide (CO) emissions has significantly decline. In ref. [15], the authors found that the introduction of the catalytic converter in 1975 resulted in a decrease of 76.3% in CO emissions. Other significant sources of CO emissions include indoor appliances that use fossil fuels. Consequently, the impact of CO exposure continues to be a public health concern. Acute and chronic CO exposure has been associated with headaches and death [16,17,18] detailed unintentional CO related deaths in the United States between 1979 and 1988. The highest death rates occurred during the winter, and 6552 unintentional deaths were related to automobile exhaust. Of these, 5432 occurred in stationary vehicles. The authors in Ref. [12]found increased numbers of cardiorespiratory complaints in Denver, Colorado, emergency departments with ambient CO levels exceeding 5 ppm over 24 hours or 11 ppm during a 1-hour period. Other research, [26] found a statistically significant increase in cancer risk among motor vehicle inspectors exposed to a time-weighted average of 10 to 24 ppm of carbon monoxide [19-25].

Nitrogen dioxide exposure has been associated with mild respiratory symptoms at low concentrations and with death in the setting of closed-space, overwhelming exposure. One of the earliest disasters attributed to NO_2 was the McConnell missile incident [12]. Three personnel were exposed to high concentrations of NO_2 after a spill during rocket fuelling. One died immediately and 2 had a severe respiratory distress syndrome. Six others in the vicinity had dyspnea, cough, and haemoptysis. Another incident of population exposure to NO_2 occurred in Minnesota during 2 ice hockey games [12]. One hundred sixteen people had dyspnea, haemoptysis, and cough within 48 hours of attending these matches, and the source was eventually identified as a malfunctioning ice resurfacer.

As such, ambient air pollutants affect not only individual's health, but also puts a high burden on the health care system and broader economy of a country [3]. The assessment of the air quality is predominantly carried out by high-end monitoring stations whose prohibitive cost limits their deployment to only a few stations per city. These monitoring stations incur high maintenance costs and are mostly located in dense areas or in the vicinity of city centres, leaving large geographical areas uncovered. Areas located far away from these monitoring stations might suffer a lower accuracy of reported values as the data is extrapolated over a wider geographical area. Therefore, designing and fabricating a low cost, but reliable IoT (Internet of Things) unit will enable sufficient monitors to be deployed across the country for air pollution monitoring and data reporting. Hence, this research work develops a low-cost sensor based IoT that is deployed to three locations, Ayeduase Gate junction, KNUST campus junction and KNUST Tech junction to monitor CO, NOx, O_3 and SO_2. The work further analyses and determines if the emissions data exceed NAAQS and hence could pose serious health threats to over 500,000 people living within the community, most of whom are students at the Kwame Nkrumah University of Science and Technology (KNUST). The results can draw university management and community leaders' attention to whether emissions standards are being exceeded and hence develop control strategy to protect human health and public welfare from transportation emissions within the locality.

2. Materials and Methods

2.1 Sampling locations

Three sampling locations within the neighbourhood of KNUST campus were identified for data collection. These are KNUST Tech junction, Ayeduase Gate junction and KNUST campus junction. The density of traffic in each subsection was obtained from vehicular counts made by 2023 third year civil engineering student of KNUST at different times of the day (from 6.00 am to 6.00 pm) during normal working day. The level of traffic pollution was assumed to be proportional to the average number of vehicles in that subsection. The study area is heavily populated with student population of about 80,000. One of the locations, KNUST Tech junction, where the IoT emissions monitor was mounted to collect emissions data and traffic count data was a major road. The remaining two subsections, Ayeduase gate junction and KNUST campus junction, are minor roads. Figures 1-4 show the three subsections. Emissions data was collected for 2 different periods, first when students were in school and second when students were out of school (on holidays).

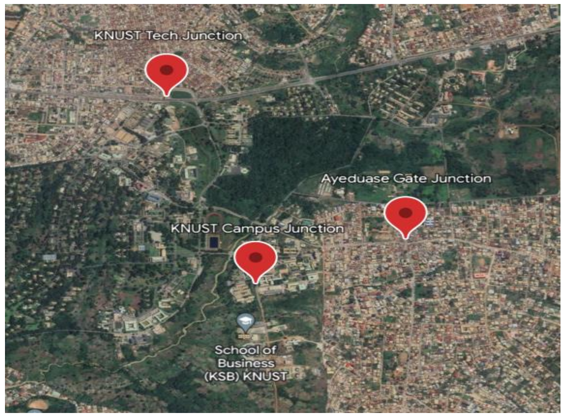

Figure 1: Map of study area with all three subsections, KNUST campus junction, Ayiduase gate junction and KNUST Tech junction

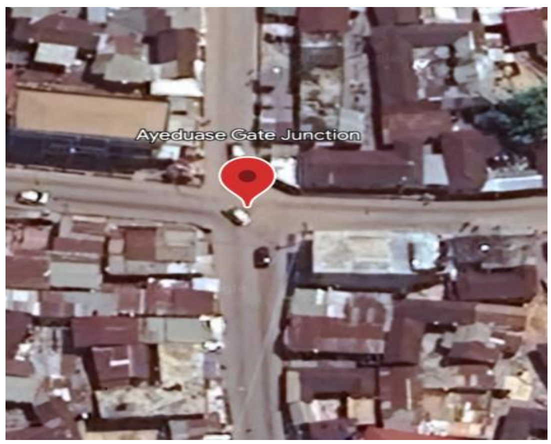

Figure 2: Study area 2, Ayeduase Gate junction

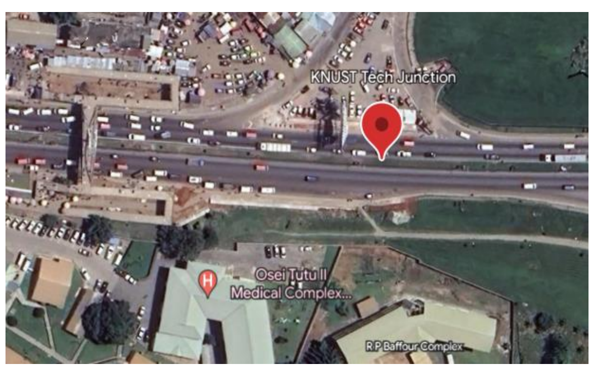

Figure 3: Study area 1, KNUST Tech Junction subsection

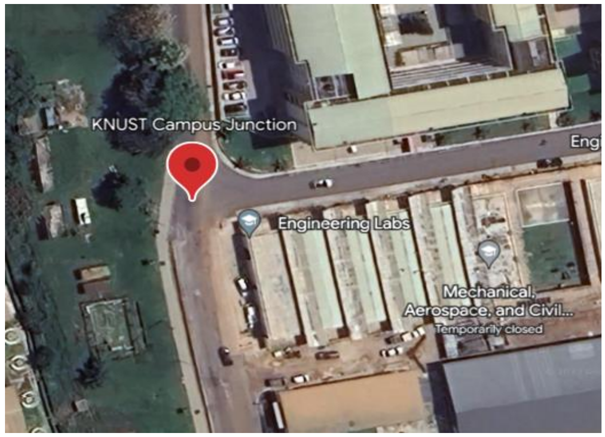

Figure 4: Study area 3, KNUST campus junction subsection

2.2 Emissions monitor (IoT) design and working principles of sensors

The emissions monitor designed consists of internal sensors such as MQ-7 (carbon monoxide sensor), MQ-131 (ozone sensor), MQ-136 (sulphur dioxide sensor), MICS-6814 (nitrogen dioxide sensor), and GY-SHT31-D (temperature and humidity sensor). The various MQ gas sensors are Resistive Chemical sensors that use the sensing resistance (Rs) of the pollutant in clean air against the load resistance (Rl) in a contaminated air to measure the gas level. The various MQ gas sensors requires calibration to function effectively (Babu and Nagaraja, 2018). The MQ-7 is a carbon monoxide (CO) semiconductor sensor which measure the concentration of CO using the changes in its resistivity. The MQ-7 carbon monoxide gas sensor consist of a tin dioxide (SnO2) thin filament insulated in an Aluminium Oxide (Al2O3) ceramic base. The measure range of the MQ-7 sensor is between 20 ppm and 2000 ppm. (Marquez-viloria, Botero-Valencia and Villegas-ceballos, 2016; Babu and Nagaraja, 2018)

The MQ-131 is an Ozone gas sensor. The MQ-131 is a Metal Oxide Semiconductor (MOS) sensor. Ozone concentration is measured by the changes in conductivity of the sensitive material of the MQ-131 sensor. The conductivity is high in clean air and decreases with increase in Ozone concentration. The sensitivity of the MQ-131 sensor increases with an increase in temperature. The MQ-131 Ozone gas sensor measures between the range of 10 ppb and 2 ppm. (Marquez-viloria, Botero-Valencia and Villegas-ceballos, 2016)

The MQ-136 Sulphur Dioxide (SO_2) gas sensor measures concentration between the range of 1 to 100 ppm (Nasution *et al.*, 2020).

The MICS-6814 gas sensor consist of a micromechanical diaphragm, an embedded heating resistor and a three separate gas sensing element top layer (Nasution *et al.*, 2020). The MICS-6814 is capable of measuring various pollutants including Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), and Ammonia (NH_3) with different independent channel for each gas. (Helton and Girão, 2020). The MICS-6814 was dedicated to Nitrogen Dioxide (NO2) pollutant for this experiment. The working range for MICS-6814 Nitrogen Dioxide (NO2) measurement is between 50 to 10000 ppb (Helton and Girão, 2020). The typical accuracy range of the MICS-6814 is ± 15 - 25 %. The sensitivity of MICS-6814 is 0.05 ppm (50 ppb) for Nitrogen Dioxide (NO_2) (Marques and Pitarna, 2019).

The GY-SHT31-D is a temperature and Relative humidity sensor. GY-SHT31-D measures temperature within the range of - 40 ^{o} C to + 125 ^{o} C, and relativity humidity range of 0 to 100 % with maximum error of 2 ^{o} C and 4 % respectively (Pitukhin, Kolesnikov and Panov, 2021). The various sensors were calibrated using libraries from the sensor manufacturers designated for the working conditions of the sensors based on the various location. The calibration of the sensor was to enhance better performance and to enhance the accuracy of the monitored emissions. Fig.5 shows a block diagram of the monitor design while Fig.6 shows various internal components including the sensors used in the monitor design and development.

Among the other various components incudes.

- Battery pack (12 V)
- A battery Management System
- A 50 W solar panel
- An Atmega 328V microcontroller unit
- A sim800I GSM module
- Im2596 buck converter
- A 28 pin IC socket
- 1N5408
- 2.54 male and female pin headers
- 16 MHz crystal
- A 22 Pico farad, 100 Nano farad capacitors
- 10 k ohms, 20 k ohms, and a 1 k ohm resistors
- A Vh3.96 connector

The sim800I GSM module was integrated into the monitor to enhance the transmission of the monitored emissions data onto a ThingSpeak cloud platform. The ThingSpeak (by Mathworks) IoT analytic platform was selected for this project due to the easiness in data download from the platform, easy monitoring, and visualization of live reported data on the platform.

On the other hand, the relationship between thermal Science and the utilization of monitored emissions data on the ThingSpeak cloud platform, developed by MathWorks [1,6]. The integration of Thermal Science and IoT analytics offers significant potential for understanding and optimizing energy systems, environmental impact, and overall efficiency [23-30]. The ThingSpeak platform provides a comprehensive framework for collecting, analyzing, and visualizing real-time data from various sensors and devices. Through this platform, monitored emissions data can be seamlessly integrated, allowing for the examination of emissions patterns, trends, and correlations with thermal processes. By leveraging the powerful analytic capabilities of ThingSpeak, researchers and engineers can gain valuable insights into the impact of thermal systems on emissions. Real-time data visualization tools enable the identification of emission hotspots, the evaluation of emission reduction strategies, and the assessment of system performance under different operating conditions [31]. Furthermore, the integration of Thermal Science principles with ThingSpeak's IoT analytics facilitates the development of predictive models. These models can aid in forecasting emissions based on thermal system inputs, allowing for proactive emission management and optimization of energy utilization. The combination of thermal science and the ThingSpeak IoT analytic platform presents a compelling opportunity to enhance our understanding of emissions in relation to thermal processes. This integration fosters advancements in energy efficiency, environmental sustainability, and informed decision-making for industries and researchers alike.

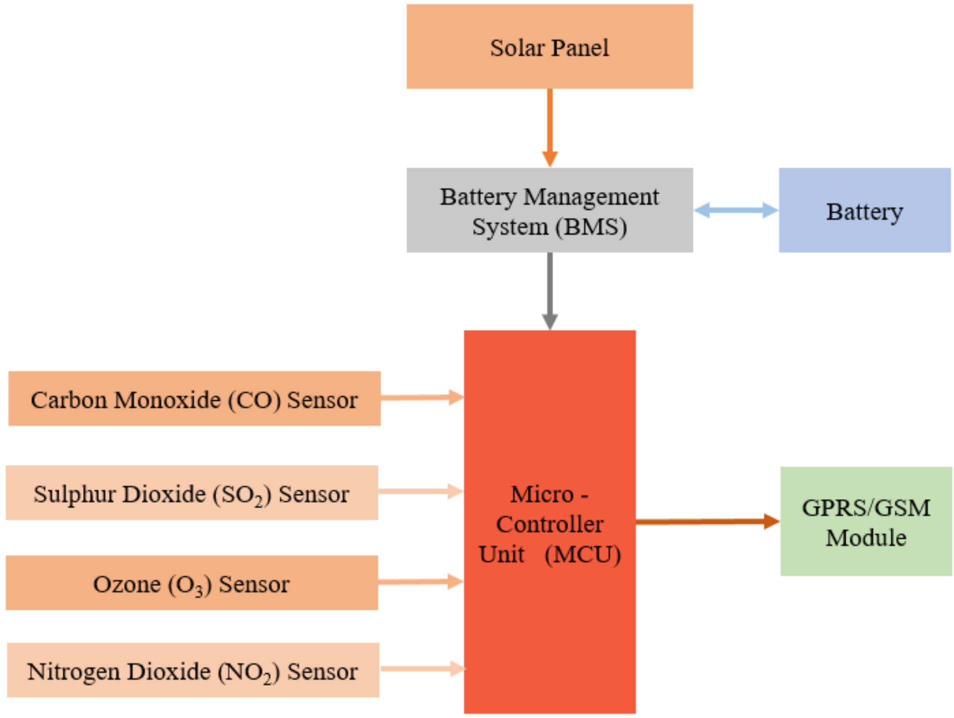

Figure 5: Block diagram of the various units of the GHG monitor

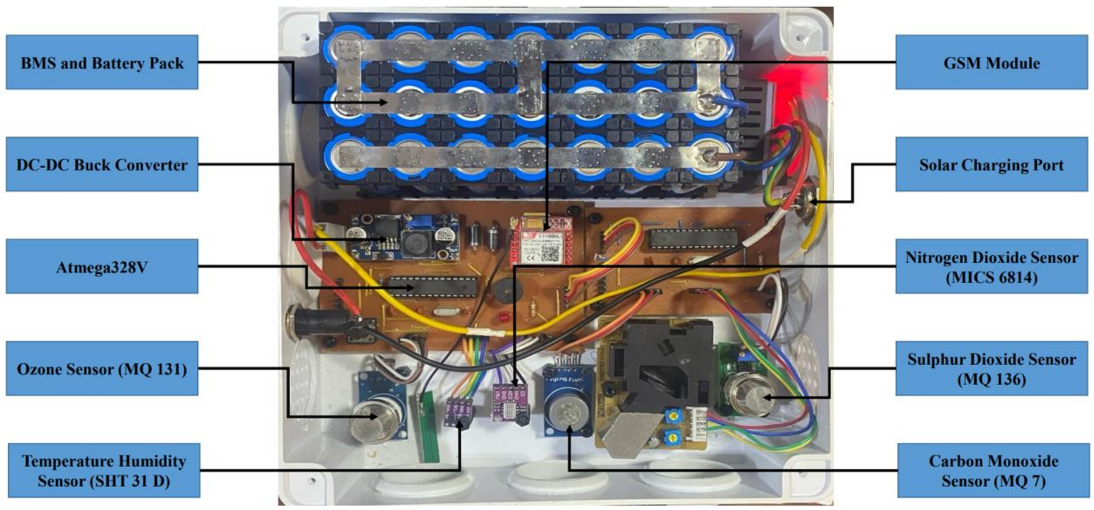

Figure 6: Internal components of the developed monitor

2.3 Monitoring Procedure

The IoT unit was deployed to each of the selected locations, Ayeduase Gate junction, KNUST campus junction and KNUST Tech junction and remained there for 1 week. The University's technicians and electricians were responsible for the installation of the unit each time it has to be moved from one location to the next. The unit has an in-built calibration system, and it is ensured that it has been reset to collect accurate data. Figure 7 shows the emissions monitor deployed to one of the locations for data collection.

Figure 7: Image of the IoT monitor deployed for data collection

3.Results and Discussions

3.1 Ayeduase Gate Junction

Daily average emissions for carbon monoxide (CO), nitrogen dioxide (NO2) and ozone (O3) are presented in Fig. 8 to Fig.10 for monitor location at Ayeduase gate junction. For each of the graphs, “in session” represents data collected within period when students were in school, and “vacation” represents data collected within period when students were on vacation. From the graphs it is observed that the in-session emissions for all days exceeded the vacation periods emissions, which is a clear indication that student in school increased the population within the community and hence increased traffic flow, which translated into increased emissions. Similar observations were made for the other two locations, KNUST campus junction (Fig. 11 to Fig.13) and KNUST Tech junction (Fig. 14 to 16). The mean daily CO emissions exceeded 9ppm for almost all the seven days except Thursday at the Ayeduase site. Similar observation was made for the KNUST Tech junction were the mean CO emissions for all the days exceeded the standard of 9ppm. These exceedances occurred when school was in session and student population were high within the community. This could pose varying degree of health problems ranging from respiratory, childbirth defects to cardiovascular to students and community. Tables 1 to 3 show the mean concentrations of CO, NO_2 and O_3 at all three sites near major road (KNUST Teck junction) and minor roads (Ayeduase gate junction and KNUST campus junction), when students are in school. It is observed from the tables that the emissions from the major road, where daily traffic flow is greatest exceeds those from the minor roads.

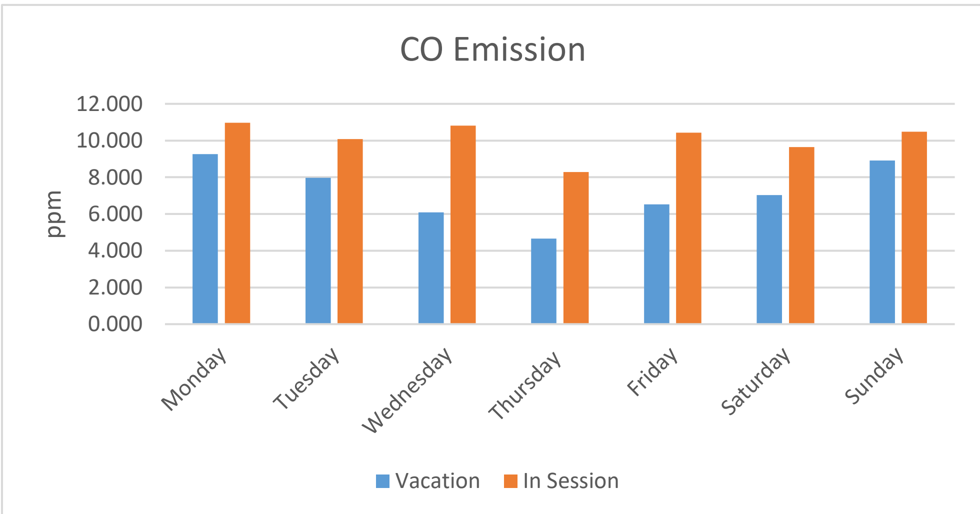

Figure 8: Mean daily concentration of CO at Ayeduase gate junction

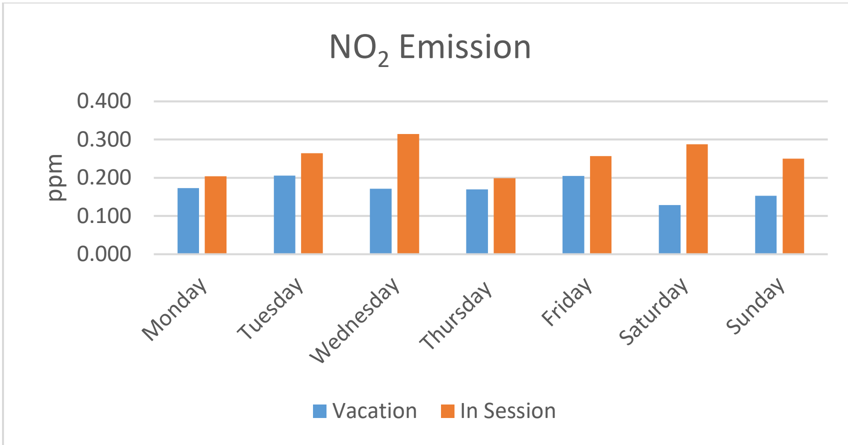

Figure 9: Mean daily concentration of NO_2 at Ayeduase gate junction

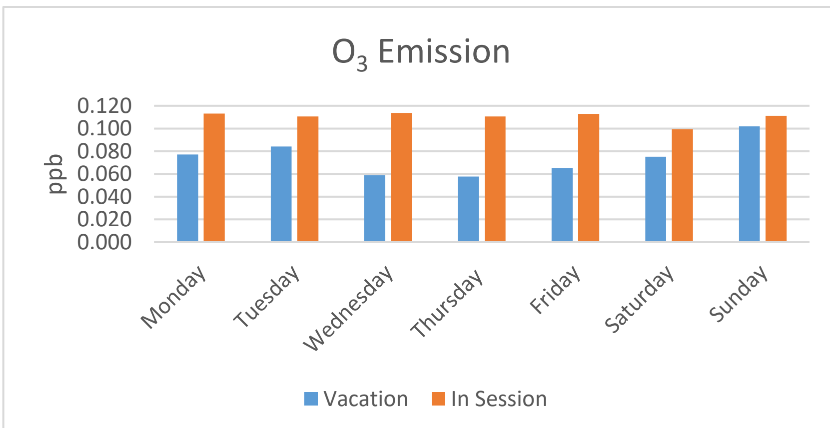

Figure 10: Mean daily concentration of O_3 at Ayeduase gate junction

3.2 KNUST Campus Junction

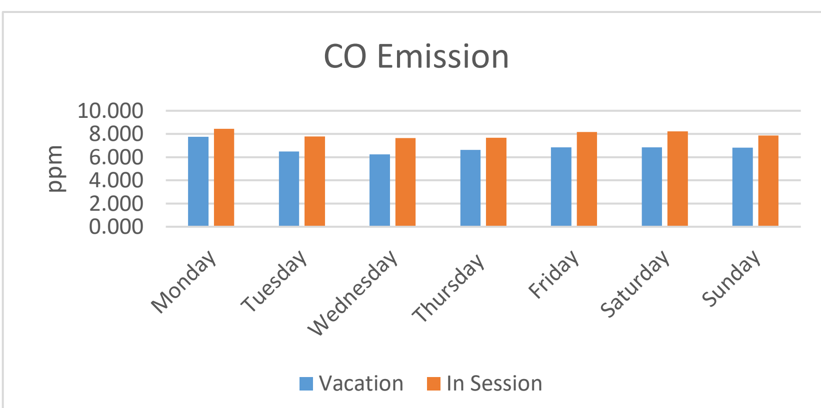

Figure 11: Mean daily concentration of CO at KNUST campus junction

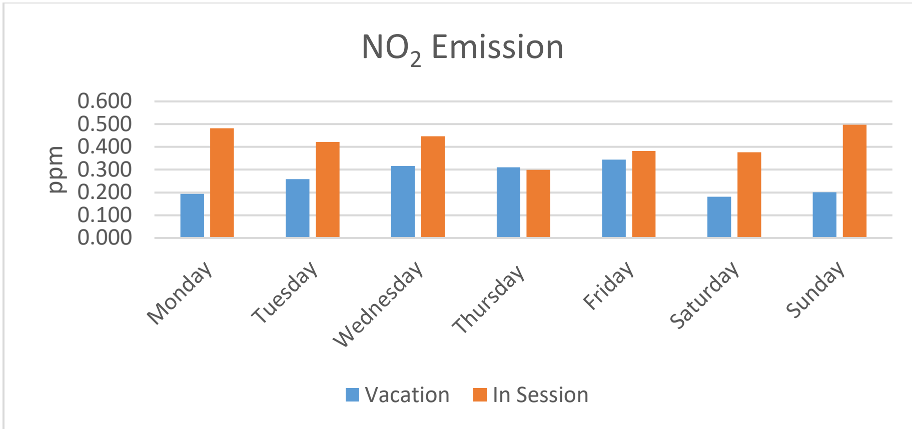

Figure 12: Mean daily concentration of NO_2 at KNUST campus junction

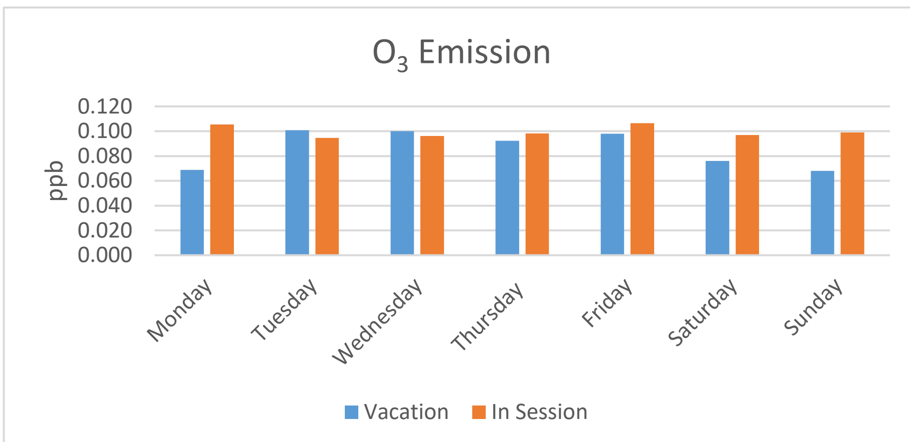

Figure 13: Mean daily concentration of O_3 at KNUST campus junction

3.3 KNUST Tech Junction

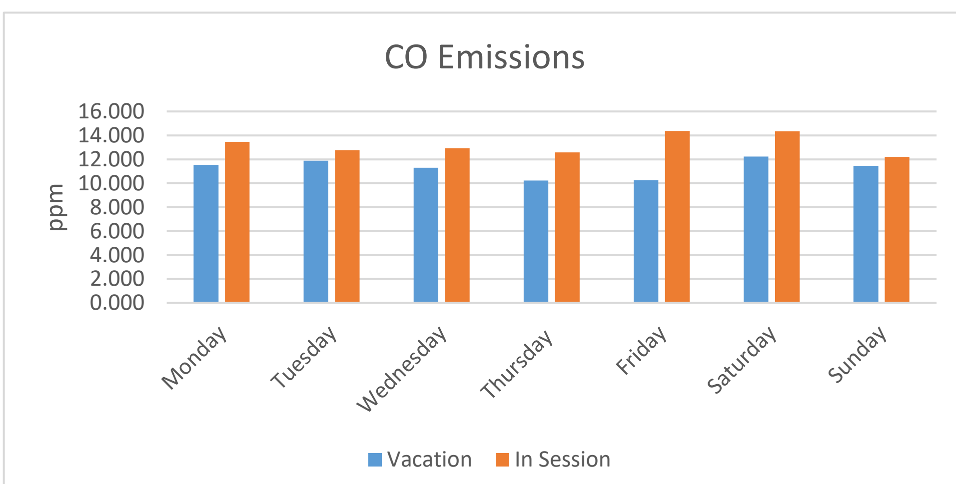

Figure14: Mean daily concentration of CO at KNUST tech junction

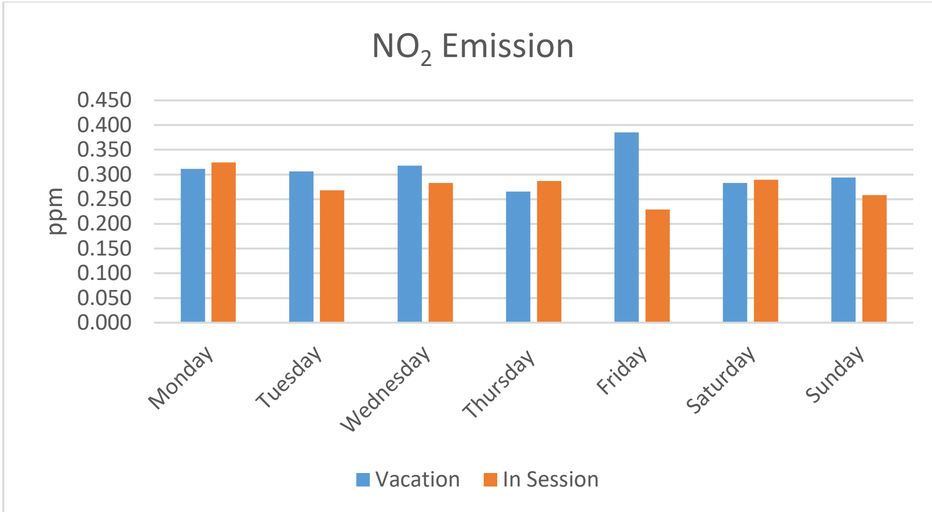

Figure 15: Mean daily concentration of NO_2 at KNUST tech junction

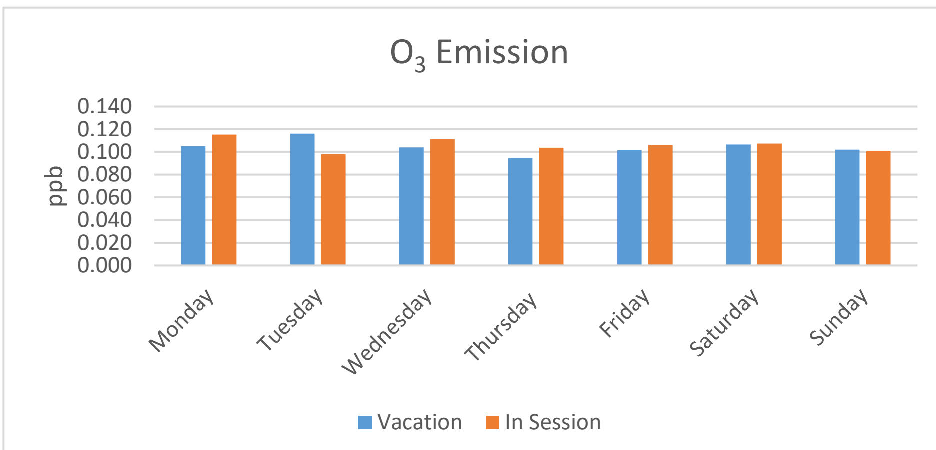

Figure 16: Mean daily concentration of O_3 at KNUST tech junction

3.4 Daily emissions on major and minor roads

The concentrations of CO, NO_2 and O_3 at monitoring sites near major and minor distributor roads are shown in Tables 1 to 3. Nearly all the daily CO emissions at monitoring location near major road recorded the highest for all the days compared with the monitoring locations near the minor roads due to high levels of traffic volume. Another reason for the high levels of CO emissions may be due to the frequencies of "stop and go" by public vehicles to pick up passengers and this may contribute to high starting emissions.

Table 1: CO emissions at major and minor roads

	IN SESSION (CO EMISSIONS) ppm						
Road	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
KNUST Tech Junction (**Major Road**)	13.5	12.8	12.9	12.6	14.4	14.3	12.2

Ayeduase gate junction (**Minor Road)**	11.0	10.1	10.8	8.3	10.4	9.6	10.5
KNUST campus junction (**Minor Road**)	8.5	7.8	7.7	7.7	8.2	8.2	7.9

Table 2: NO_2 emissions at major and minor roads

	IN SESSION (NO_2 Emissions) ppm						
Road	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
KNUST tech Junction (**Major Road**)	0.325	0.268	0.283	0.287	0.229	0.290	0.258
Ayeduase gate junction (**Minor Road**)	0.204	0.264	0.314	0.199	0.257	0.288	0.250
KNUST campus junction (**Minor Road**)	0.481	0.421	0.446	0.299	0.382	0.377	0.497

Table 3: O_3 emissions at major and minor roads

	IN SESSION (O_3 Emissions) ppb						
Road	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
KNUST Tech Junction (**Major Road**)	0.113	0.111	0.114	0.111	0.113	0.099	0.111
Ayeduase gate junction (**Minor Road**)	0.105	0.095	0.096	0.098	0.106	0.097	0.099
KNUST campus junction (**Minor Road**)	0.115	0.098	0.111	0.104	0.106	0.107	0.101

3.5 Mean weekly concentration levels of emissions

Table 4: Mean weekly levels of CO (ppm) (In session)

Road	Mean	Range
KNUST Tech Junction	13.2	9 - 16
Ayeduase gate junction	10.1	8 - 16
KNUST Campus junction	8.0	6 - 10

Table 5: Mean weekly levels of NO_2 (ppm) (In session)

Road	Mean	Range
KNUST Tech Junction	0.277	0.142 - 0.731
Ayeduase gate junction	0.254	0.076 - 0.656
KNUST Campus junction	0.415	0.100 - 0.798

Table 6: Mean weekly levels of O_3 (ppb) (In session)

Road	Mean	Range
KNUST Tech Junction	0.106	0.070 - 0.154
Ayeduase gate junction	0.110	0.078 - 0.153
KNUST Campus junction	0.100	0.070 - 0.130

3.6 Traffic flow volume collected at the three monitoring locations

Table 7 shows the hourly number of vehicles count that passed at each of the three junctions on a particular day within the period when pollution monitoring was conducted. Number of vehicles passing the junctions were counted during the morning hours of 7am – 10 am and then during the evening hours of 3pm – 6 pm. The total number of vehicles passing the KNUST tech junction for the day was 6572, for Ayeduase gate junction was 2531 and for KNUST campus junction 1315. This is evident that the daily concentration of pollutants recorded is directly proportional to the traffic flow volume. That is pollution levels increases with increasing volume of traffic flow.

Table 7: Hourly traffic flow volume

	Hourly Traffic flow volume (**Daily Total)**						
Road	7-8 am	8-9am	9-10am	3-4pm	4-5pm	5-6pm	**TOTAL**
KNUST Tech Junction (**Major Road**)	888	939	954	945	1195	1651	**(6572)**
Ayeduase gate junction (**Minor Road**)	286	400	438	404	693	310	**(2531)**
KNUST campus junction (**Minor Road**)	76	193	158	214	344	330	**(1315)**

4. Conclusion

In conclusion, the findings of the study showed the importance of vehicular traffic as a major source of air pollution. The concentrations of pollutants were higher at the selected locations when school was in session, and when traffic volume increases due to students' commutation to and from university faculties. Therefore, further detailed investigation may be warranted for university. In addition to increased emissions matching traffic flow volume, there is noticeable variation in the concentrations of pollutants on major roads as compared to minor roads.

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