

Ambient Air Pollution Monitoring and Health Studies Using Low-Cost Internet of Things 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, O₃, SO₂, NO₂, 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, Ayeduse 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, NO₂, O₃ and SO₂ 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, NO₂ and O₃ concentrations measured at the selected locations when school was in session and during vacation were presented on histogram. The mean weekly concentrations of CO, NO₂ and O₃ were also estimated as 13.2ppm, 0.277ppm and 0.110ppb respectively at KNUST Tech junction; 10.1ppm, 0.254ppm and 0.100ppb respectively at Ayeduse gate junction; and 8.0ppm, 0.415ppm and 0.106ppb 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 devise means of curbing it.

Keywords – IoT Monitor, Criteria Pollutants, Health Impact, Emission Standards, KNUST Campus Junction.

I. 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 [1-2]. 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 [1, 3-5]. 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.

Ambient carbon monoxide (CO) levels have risen, during times of high automobile volumes [6]. Since the introduction of catalytic converters in motor vehicles, carbon monoxide (CO) emissions have significantly declined. Chan et al., [7] and Mott et al., [8] 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 [8]. In [9] 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 [10] 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 researches [11] 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.

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 NO₂ was the McConnell missile incident [6]. Three personnel were exposed to high concentrations of NO₂ after a spill during rocket fueling. One died immediately and 2 had a severe respiratory distress syndrome. Six others in the vicinity had dyspnea, cough, and hemoptysis. Another incident of population exposure to NO₂ occurred in Minnesota during 2 ice hockey games [6]. One hundred sixteen people had dyspnea, hemoptysis, and cough within 48 hours of attending these matches, and the source was eventually identified as a malfunctioning ice resurface [12].

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 [14]. 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 centers, leaving large geographical areas uncovered [13]. 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, Ayeduae Gate junction, KNUST campus junction and KNUST Tech junction to monitor CO, NO₂, O₃ and SO₂ [15]. 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 [16].

II. MATERIALS AND METHODS

Sampling Locations

Three sampling locations within the neighbourhood of KNUST campus were identified for data collection. These are KNUST Tech junction, Ayeduae 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, Ayeduae gate junction and KNUST campus junction, are minor roads. **Fig 1** to **Fig 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).

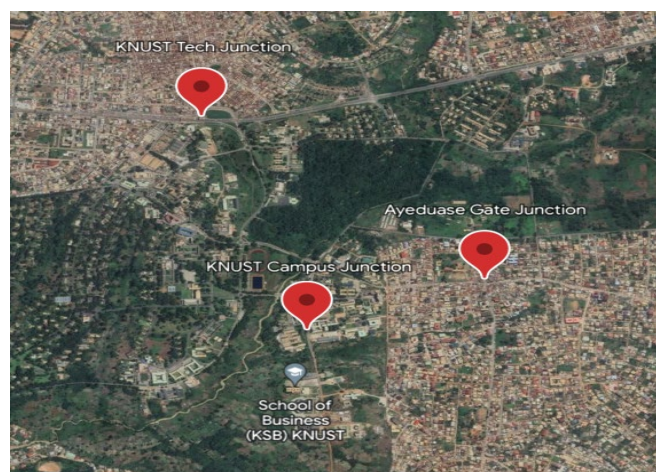
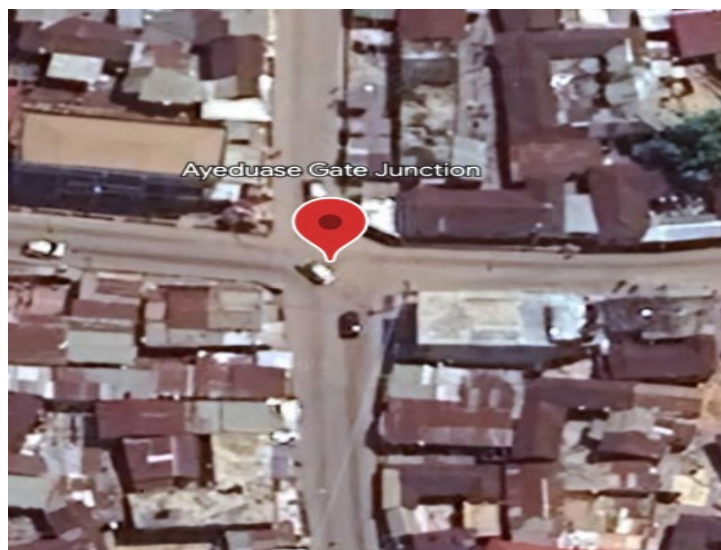


Fig 1. Map of study area with all three subsections, KNUST campus junction, Ayiduae gate junction and KNUST Tech Junction



F. Study area 2, Ayeduase Gate Junction

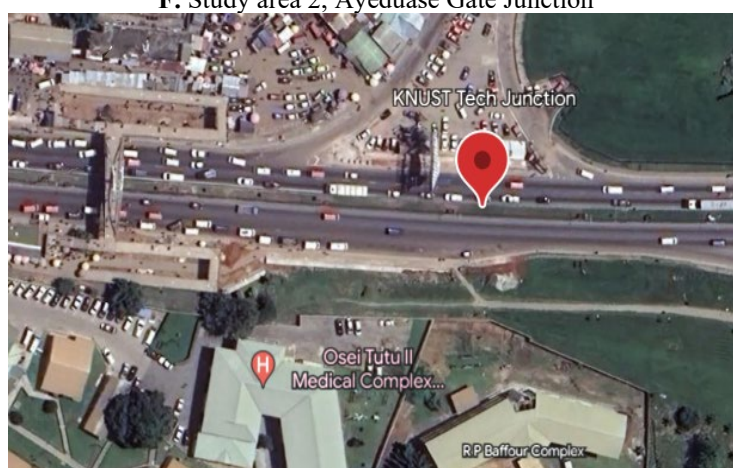


Fig 3. Study area 1, KNUST Tech Junction Subsection

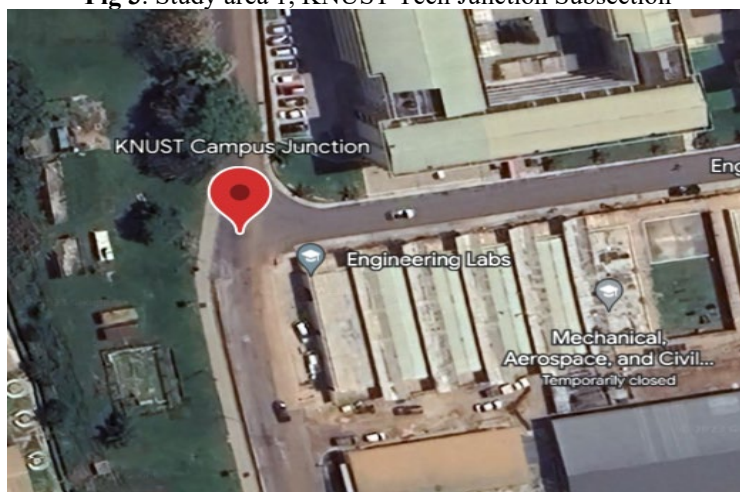


Fig 4. Study area 3, KNUST Campus Junction Subsection

Emissions Monitor 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 (R_s) of the pollutant in clean air against the load resistance (R_l) in a contaminated air to measure the gas level. The various MQ gas sensors require calibration to function effectively [17].

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 (SnO_2) thin filament insulated in an Aluminium Oxide (Al_2O_3) ceramic base. The measure range of the MQ-7 sensor is between 20 ppm and 2000 ppm [17-18].

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 [19].

The MQ-136 Sulphur Dioxide (SO_2) gas sensor measures concentration between the ranges of 1 to 100 ppm [20].

The MICS-6814 gas sensor consists of a micromechanical diaphragm, an embedded heating resistor and a three separate gas sensing element top layer [20]. 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 (NO_2) pollutant for this experiment. The working range for MICS-6814 Nitrogen Dioxide (NO_2) measurement is between 50 to 10000 ppb [21]. The typical accuracy range of the MICS-6814 is $\pm 15 - 25 \%$. The sensitivity of MICS-6814 is 0.05 ppm (50 ppb) for Nitrogen Dioxide (NO_2) [18].

The GY-SHT31-D is a temperature and Relative humidity sensor. GY-SHT31-D measures temperature within the range of -40°C to $+125^\circ\text{C}$, and relativity humidity range of 0 to 100 % with maximum error of 2°C and 4 % respectively [22].

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.

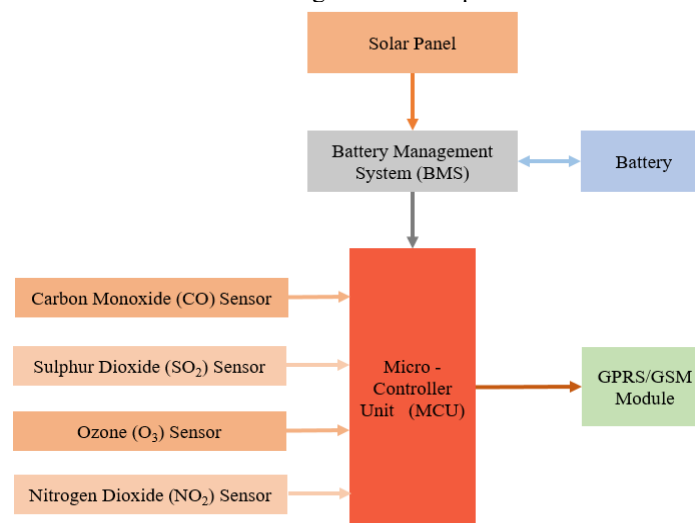


Fig 5. Block Diagram of the Various Units of the GHG Monitor.

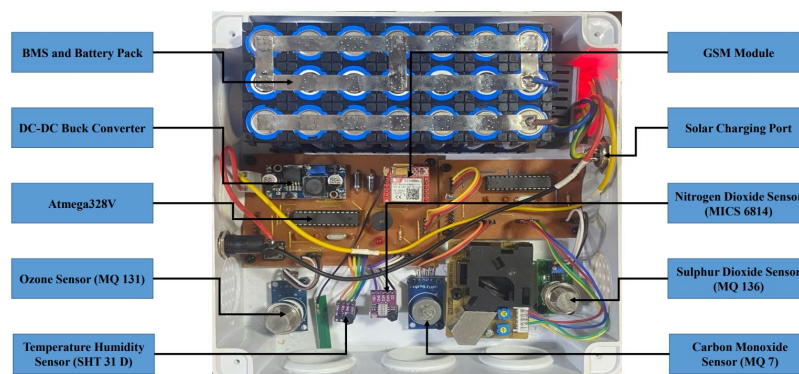


Fig 6. Internal Components of the Developed Monitor

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
- A 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.

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. **Fig 7** shows the emissions monitor deployed to one of the locations for data collection.



Fig 7. Image of the IoT Monitor Deployed for Data Collection

III. FINDING AND RESULTS

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 **Fig13**) and KNUST Tech junction (**Fig 14** to **Fig 16**), except for a couple of days where the NO₂ and O₃ concentrations for the vacation period slightly exceeded or equalled the corresponding concentrations when students were in school.

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 where 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.

Table 1 to Table 3 show the mean concentrations of CO, NO₂ and O₃ at all three sites near major road (KNUST Tech 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.

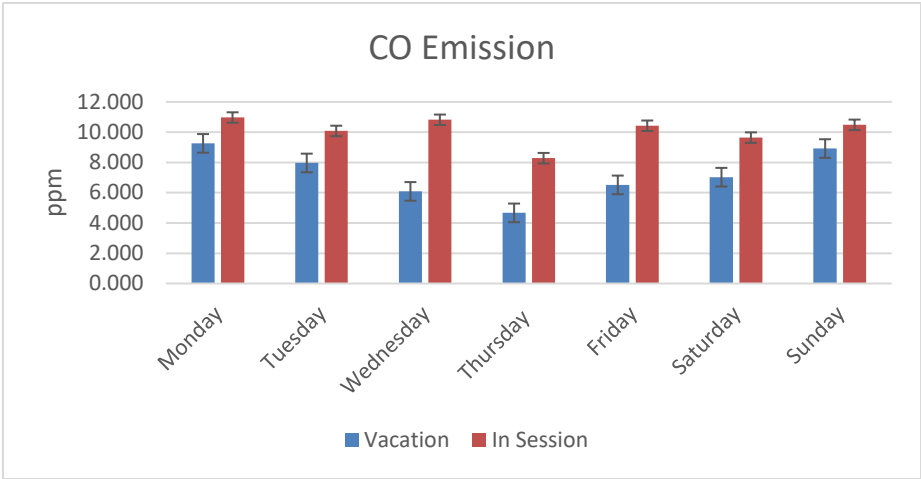


Fig 8. Mean Daily Concentration of CO at Ayeduase Gate Junction

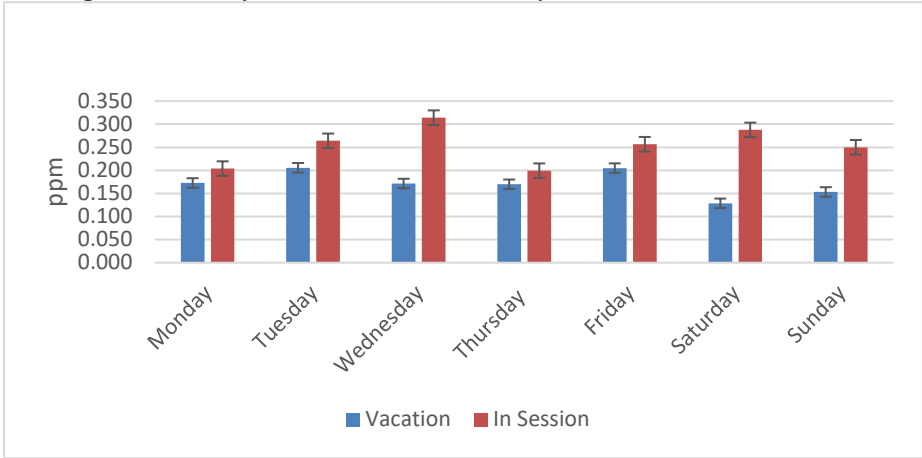


Fig. 9 Mean daily concentration of NO₂ at Ayeduase Gate Junction

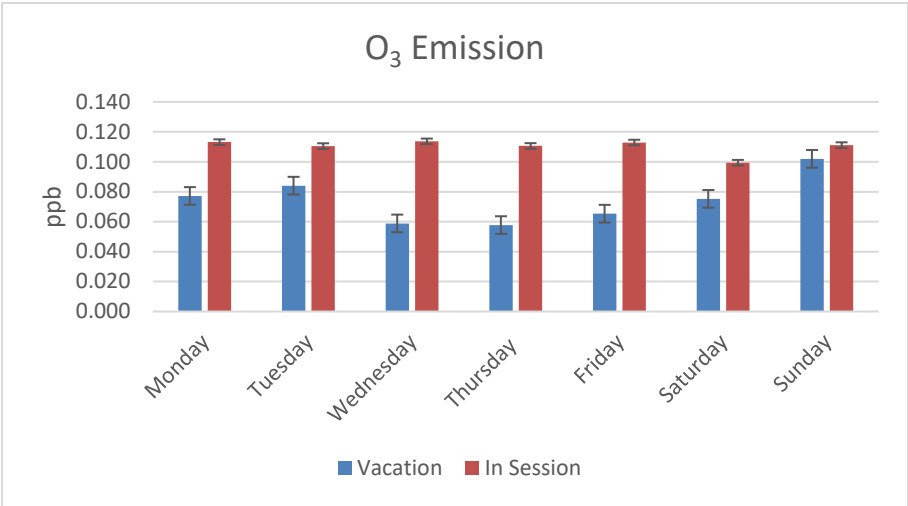
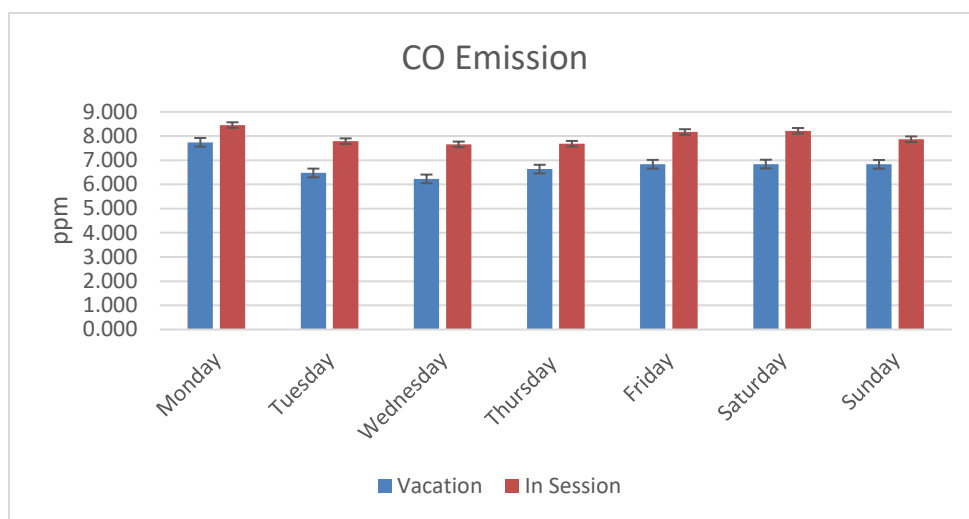
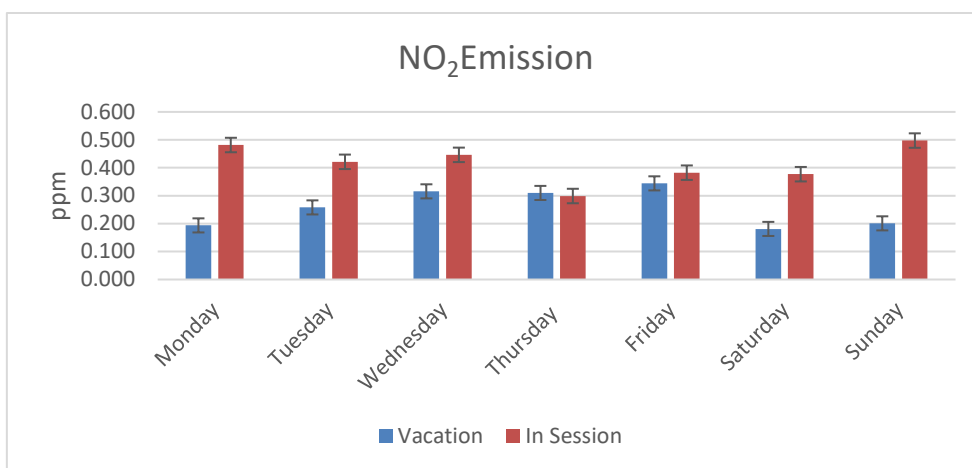
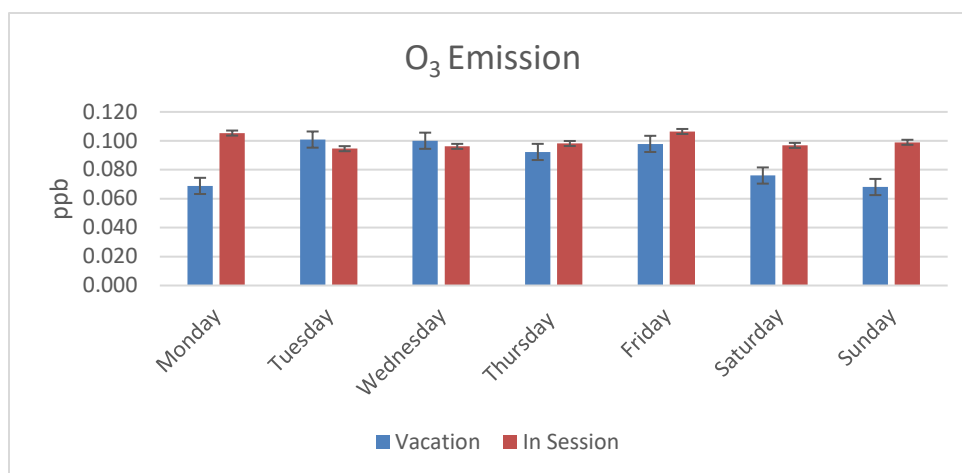


Fig 10. Mean Daily Concentration of O₃ at Ayeduase Gate Junction

**Fig 11.** Mean Daily Concentration of CO at KNUST Campus Junction**Fig 12.** Mean Daily Concentration of NO₂ at KNUST Campus Junction**Fig 13.** Mean Daily Concentration of O₃ at KNUST Campus Junction

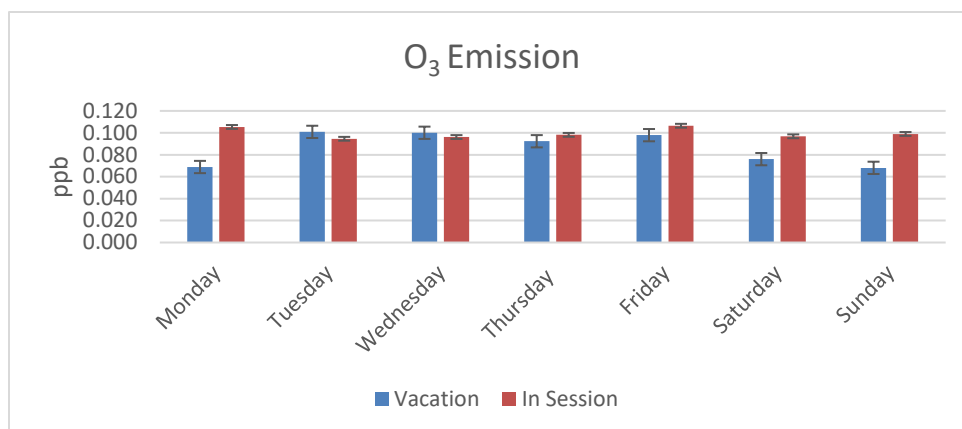


Fig 14. Mean Daily Concentration of CO at KNUST Tech Junction

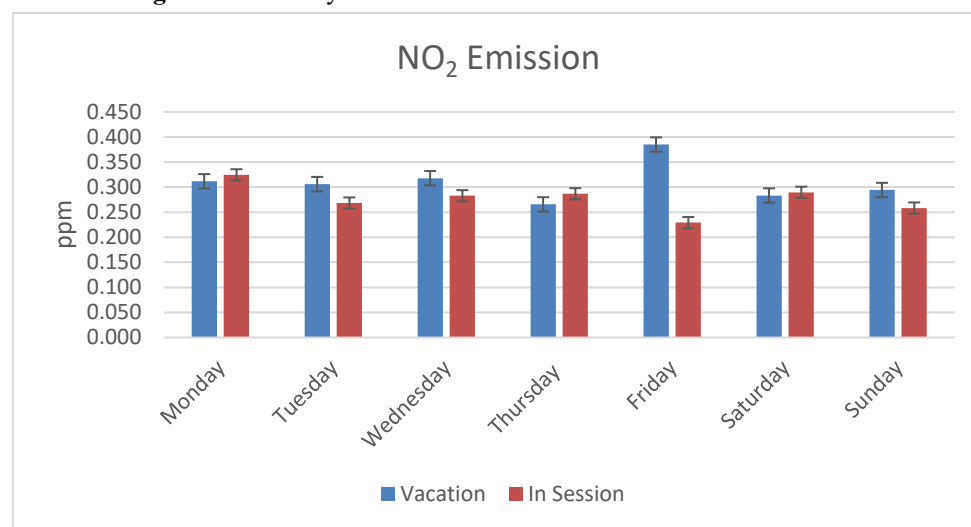


Fig 15. Mean Daily Concentration of NO₂ at KNUST Tech Junction

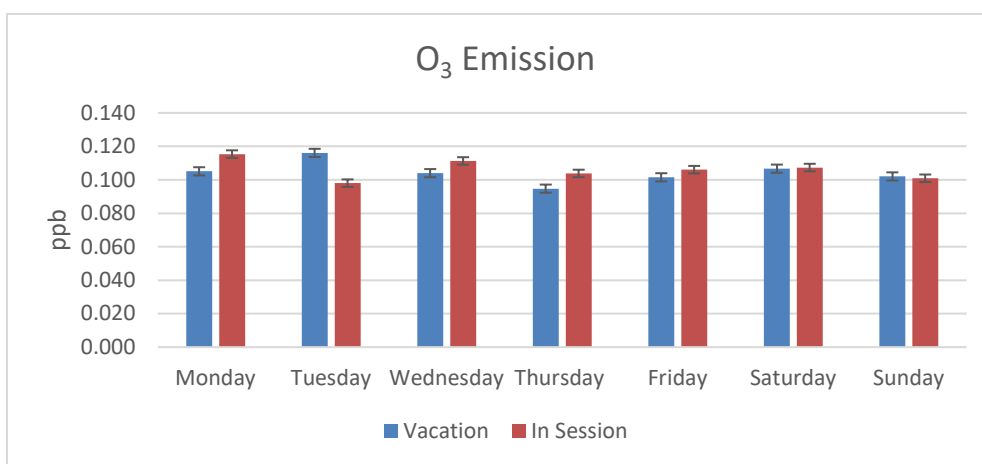


Fig 16. Mean Daily Concentration of O₃ at KNUST Tech Junction

Daily Emissions on Major and Minor Roads

The concentrations of CO, NO₂ and O₃ at monitoring sites near major and minor distributor roads are shown in **Table 1** to **Table 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
Ayeduse 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. NO₂ 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
Ayeduse 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. O₃ 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
Ayeduse 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

Mean Weekly Concentration Levels of Emissions from **Table 4** to **Table 6**.

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

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

Table 5. Mean weekly levels of NO₂ (ppm) (In session)

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

Table 6. Mean weekly levels of O₃ (ppb) (In session)

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

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 Ayeduse gate junction was 2531 and for KNUST campus junction 1315. This is evident that the average daily (**Table 1-3**) and/or weekly (**Table 4-6**) concentration of pollutants recorded is directly proportional to the traffic flow volume. That is pollution levels increases with increasing volume of traffic flow. The only exception is the average daily and weekly concentrations of NO₂ at KNUST campus junction (**Table 2 and Table 5**) supposed to be a minor road with low traffic volume yet has higher emissions than the major road (KNUST tech junction). This might be due to a number of factors including heavy traffic presence at the nearby traffic light, which may have contributed to frequent “stop and go” emissions during the period emissions data were being collected.

Table 7. Hourly Traffic Flow Volume

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

IV. CONCLUSIONS

In conclusion, the research study developed a low-cost IoT monitor which was used to measure emissions at three locations within the KNUST community. The findings from the emissions data analyzed 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. 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. Therefore, further detailed investigation may be needed to confirm the association of high vehicular emissions and students’ health impacts, and the findings could inform university authorities of the need to provide low-cost IoT – monitors that could alert authorities when threshold emissions levels are being exceeded.

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Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

Funding

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Competing Interests

There are no competing interests.

Reference

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