Measurement of Air Pollution of a Nigerian Industrial City using a Wireless Sensor Network

Kelvin.O.Ovabor[1] and Simeon.T.Apeh[2]

[1,2]Computer Engineering Department,
University of Benin
Benin City,
Nigeria.

Email: [1]ovabor.k@nafdac.gov.ng, [2]apeh@uniben.edu

ABSTRACT

Lagos is the most industrialized state in Nigeria with 68-80% of the country's industries located therein. Industrial activities take place in this city without paying little or no attention to the environment. The objective of this paper is to describe the use of an air pollution monitoring system using wireless sensor network (WSN) that can be easily deployed in highly polluted areas of Lagos. This system would measure the various air pollutants concentration profile of a location, generate data to plot graphs. This will help to deduce the correlation of each pollutant with other chosen factors to determine environmental risk assessment for specific geographical zone or area. To achieve these objectives, the design method is to design a wireless sensor network with two sensor nodes. Each nodes design consists of the group of sensors, Arduino processor board, GSM, and GPS modules. Each node is expected to sense pollutants, convert and process the output and then transmit to the remote base station. The expected results would show data of each sensor for each location and graphs of response and developed risk assessment model for each test location. Moreover, it possible for the public to have access to the air pollution monitoring results in real time as it would contribute to public significance.

Keywords: *Air pollution, Wireless sensor networks, Pollutants, Environmental risk, public health, Air quality*

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1. INTRODUCTION

A sensor is a device that converts physical parameters like temperature, heat, humidity, etc processes into electrical quantities like voltage and current. When sensors measure these parameters, they create a link with both the physical world and digital world thereby capturing and revealing real-world phenomena. This is further converted into a form that can be processed and stored [1]. When many sensors cooperatively monitor large physical environments, they form a wireless sensor network [2]. A Wireless Sensor Network (WSN) is a distributed network that is made up of a large number of distributed, self-directed, and tiny, low-powered devices called sensor nodes alias motes. WSN is made up of many spatially dispersed, petite, battery-operated, embedded devices that are networked to supportively collect, process, and convey data to the users, with its computing and processing capabilities [1]. WSN application into pollution monitoring is very important and pertinent due to the increasing side effects including climate change, greenhouse gases effect, diseases and ailments, birth deformities, acid rains etc. [3]. The use of WSN in monitoring applications as in air pollution is very important. Air pollution monitoring and the use of indicators are standard in many aspects of government and business practice as a means of assessing problems, developing policy, and measuring progress [1,3]. Air pollution causes some gases in the atmosphere to exist at higher-than-normal conditions, and this can be seriously harmful to human health and the environment. Examples of these gases include the following:

i. Nitrogen oxides (NOx)
ii. Sulfur oxides (SOx)
iii.Carbon monoxide (CO)
iv. Particulate matter (PM),
v. Photochemical oxidants (e.g., ozone)
vi. Lead (Pb),
vii. Along with a variety of airborne heavy metals and volatile organic compounds (VOCs).

It is often a combination of both natural factors as well as human activities that lead to highly unhealthy conditions in air quality [3]. Air pollution has long been recognized as the most fatal form of pollution due to increasing pollution levels as a result of urbanization and growth. It has negative short- and long- term effects on human health that would deter people from moving to cities thereby impairing economic growth. It is important to reduce the effect of air pollution [3,4]. The aim of this paper is to measure air pollution of a Nigerian Industrial city using a wireless sensor network with Lagos state as case study

2. STUDY AREA

The foremost industrial states in Nigeria are Lagos, Rivers, Kano and Kaduna states with Lagos having the largest population density of them all. Lagos state also has the highest concentration of industries, with well over seven thousand medium and large- scale industrial establishments [5]. There is a claim that about 70- 80% of the manufacturing facilities operating within the medium and large-scale industries are located there in Lagos. The major industrial estates in Lagos are: Ikeja, Agidingbi, Amuwo Odofin (industrial), Apapa, Gbagada, Iganmu, Ijora, Ilupeju, Matori, Ogba, Oregun, Oshodi/Isolo/Ilasamaja, Surulere (light industrial) and Yaba [6,7,8].

The figure 1a shows Lagos state and its environs [5].

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Figure 1a. Map of the Ikeja industrial Estate Study Area

The study area as shown on the Google map has a total area of 7.52km^2 (2.51 mi) and a total distance of 10.47km and its GPS coordinates are 6.63026, 3.34569 north, 6.2011, 3.36136 East, 6.61594, 3.33544 West, 6.0016, 3.34668 South

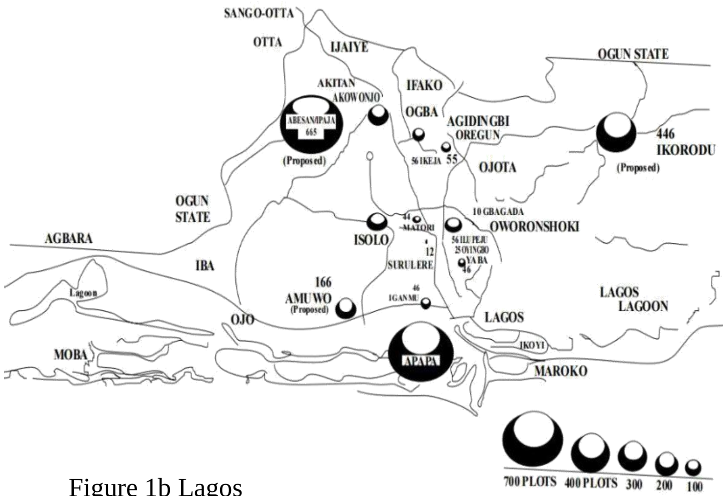

Figure 1b Lagos

Figure 1a shows the Google map of the Ikeja industrial Estate. Figure 1b shows the area that was mapped out forthe Air pollution test

3. METHODOLOGY

Individual sensors to measure air pollutants concentration in the Environment which are CO, NO2 and SO2 were designed as a sensor node with processing capability as part of the wireless sensor network architecture. Several nodes in a location- region were connected to a coordinator and to the gateway and from there sent to the base station central control system that collects the data from each sensor nodes from test sites and wirelessly through WSN. The sensors were connected to signal conditioner circuits designed for proper voltage level conditioning before their outputs were converted to digital for processing. ATMEGA328P and Arduino UNO board was the controller, used with the low- cost sensors and ETD-868-32T LoRa wireless module made up the sensor nodes. Each sensor nodes was designed and constructed with these components and deployed over the study area. To sustain continuous operation, each sensor module had a solar panel and battery backup. The program codes for the sensor nodes with the

ATMEGA328P was developed using Arduino IDE and downloaded to all the nodes with their pre- assigned address for identification.

The WSN topology that was used was the hierarchical 3 tier/level due to its advantages of low loss of data. The nodes were organized into clusters with pre-assigned cluster heads or coordinators. The cluster heads control communication within its cluster and communicate with the gateway and gateway to the base station. The WSN was set up to monitor the air pollutants and through the cluster head/ coordinators and gateway send the data to the base station. The base station was equipped with a datalogger program that receives the data and stores the information in excel spreadsheet. The base station with computer serving as the server has all relevant software with database program to record the data for future analysis. This setup was designed and scaled to standard for this research work. The test apparatus was set up to height 1.5 to 2m above ground level, height of average human breathing zone. At this height, the concentration level of the pollutants does not interfere with other factors in the environment. These tests were carried out in three sessions: morning (7.00am-8.00am), afternoon (1.00pm- 2.00pm) and evening (4.30-5.30pm) at an interval of one hour for each session.

4. LITERATURE REVIEW

WSNs have been successfully applied in various application domains such as:

Military applications: Wireless sensor networks can be applied in military command, control, communications, computing, intelligence, battlefield surveillance, reconnaissance and targeting systems[9].

Transportation: WSNS alerts divers of traffic problems in real-time by feeding transportation models [10].

Health applications: Some of the health applications for sensor networks WSNs find its application in terms of integrated patient monitoring, diagnostics, and drug administration in hospitals, tele-monitoring of human physiological data, and tracking & monitoring doctors or patients inside a hospital [11].

Structural monitoring: WSNs can be utilized to monitor the movement within buildings and. assets remotely without the need for costly site [12].

Industrial monitoring: Wireless sensor networks have been developed for machinery condition-based maintenance (CBM) so as to save cost and create room for morefunctionalities. [9,13].

Agricultural sector: This can be seen in the area of Irrigation automation which enables more efficient water use and reduces waste [14,15].

Ambient air pollution in urban cities in sub-Saharan Africa (SSA) is an important public health problem with models and limited monitoring data indicating high concentrations of pollutants such as fine particulate matter (PM2.5). On most global air quality index maps, however, information about ambient pollution from SSA is scarce [16].

It is important to establish the setting of the environment when considering the type of low-cost sensors to be deployed. The conditions such as availability of electricity for powering sensors, internet connection (to upload data online in near real time), safety of the devices, weather conditions (humidity or extreme weather) are important considerations for sensor deployment. Applying these low-cost technologies offers a potential opportunity for long-term exposure measurements and determination of drivers/sources of air pollutionin SSA [16,17].

The authors in [17] present a Wireless Sensor Network (WSN) architecture deployed to monitor air pollution. In this work i.e. [17], pollution data w analyzed to determine the optimal positions of sensors while reducing the node deployment cost. Furthermore, the discussion in [17], does not address the concern of sensor node power consumption and other risk factors associated with the pollutants.

This author in [18] proposed a WSN network architecture enabling the monitoring of air pollution. The proposed network was designed to enable acquired data to be utilized in making decision about air quality and human health in smart cities. In the proposed network architecture, the sensor node acquires air pollution data and sends the acquired data to a server entity. The transmission of data to this server entity is realized via terrestrial wireless networks. Furthermore, the discussion in [18] does not address air pollution profiling and the risk factors.

The author in [19] discussed the potentials of wireless sensor network technology in realizing sustainable development in Nigeria. He went further to examine how WSNs can be employed to improve access to quality health services, increased food production through precision agriculture to a better quality of human resources. The discussion in [19], does not address technological design and Implementation of WSNs in realizing the sustainable development in Nigeria.

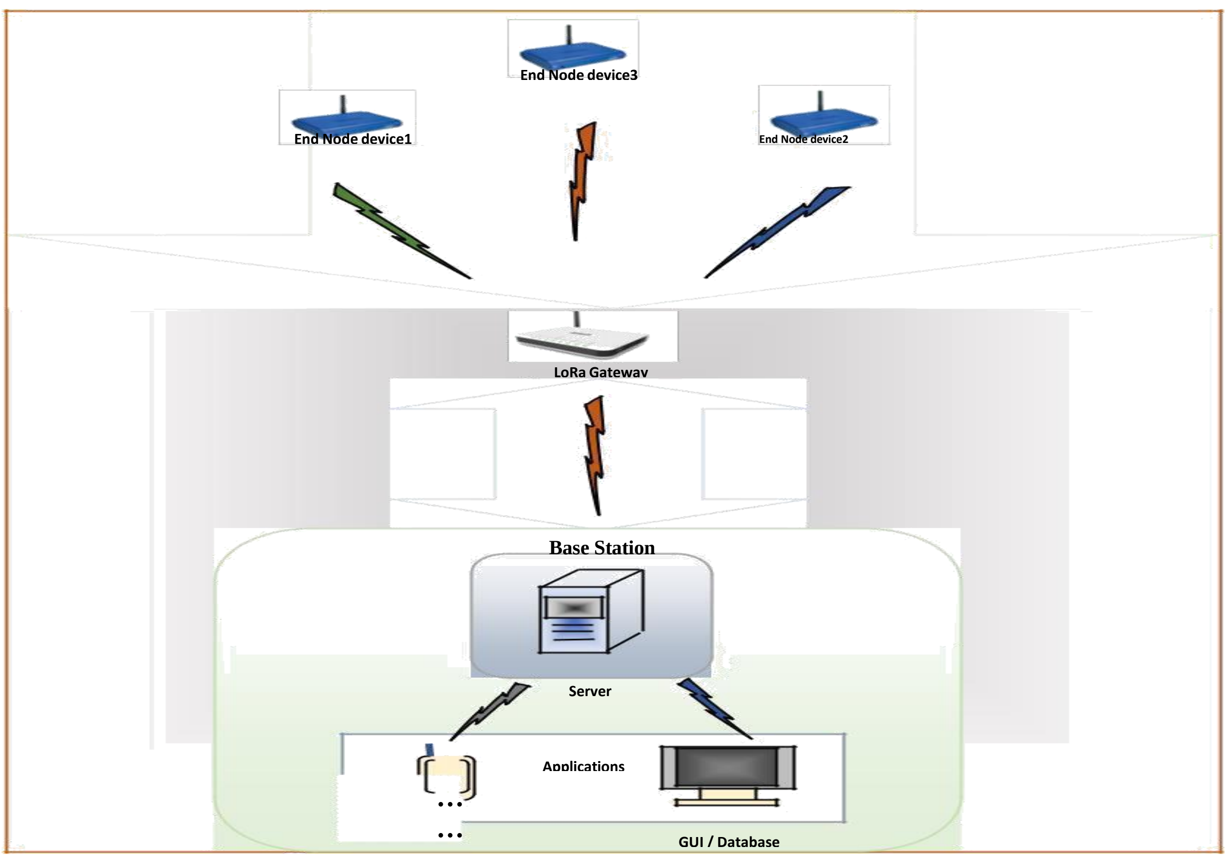

Fig 2. Wireless Sensor Network (WSN) based Air Pollution and Reporting System Architecture

The block diagram of figure 2 depicts the wireless sensor network (WSN) application in air pollution monitoring and reporting architecture with concept as embarked on this study. It shows three nodes and a gateway and each node consists of several gas sensors. The sensor nodes or end devices send their sensor data to the gateway they are tuned to through necessary configuration settings. The gateway eventually collates all sensor node data after receiving data from the nodes and sends it to the base station.

The remote base station also referred to the computer systems that serves as the server or data hub. The server has installed software with developed applications to handle database and data presentation through graphic user interface (GUI) for human-machine interaction (HMI). The applications in the server stores information of the network sensor nodes, sensor locations, time, and date of transmissions for data reception. The base station is equipped with a datalogger program that receives the data and stores the information in excel spreadsheet.

The Major functional blocks of the system are listed as:

i Sensor Nodes
ii. Gateway
iii. Remote Base Station (Server)

Table 1: Results for Zone1for a typical warm day with average temperature of 28^{o}C and Humidity of 65%

Time	CO	NO_2	SO_2	Temperature	Humidity
7.09	6.9	0.072	0.32	26	71
8.10	9.9	0.084	0.33	27	69
9.09	10.7	0.09	0.48	27	70
10.09	10.5	0.086	0.65	28	67
11.10	9.9	0.089	0.69	29	63
12.09	9.7	0.085	0.77	30	62
13.09	9.3	0.083	0.86	31	60
14.09	9.2	0.087	0.89	32	59
15.10	9.5	0.090	0.95	33	57
16.09	11.2	0.095	0.98	33	54
17.10	11.8	0.096	1.07	30	58
18.09	11.2	0.092	1.03	29	62
19.09	10.8	0.083	0.98	27	64
20.10	9.2	0.076	0.78	27	66
21.09	8.9	0.071	0.74	27	67
22.09	7.8	0.049	0.60	27	70
23.09	6.3	0.036	0.51	26	73
0.09	5.2	0.026	0.30	26	73
1.10	4.1	0.025	0.21	26	74
2.09	3.7	0.018	0.11	25	76
3.09	3.1	0.015	0.8	25	77
4.09	3.4	0.021	0.3	25	78
5.09	5.4	0.028	0.2	25	76
6.10	6.7	0.046	0.5	26	72
Average	8.1	0.064	0.63	27	65

Basically, real-time ambient air pollutant concentrations during measurements always have random spatial behavior that affects interpretation of data hence the data presented were for everyone hour as programmed. The extra 9 to 10 seconds were for the gas sensor pre-heating time as the main code starts the process on the hour. The table 1 shows the variation of all gas pollutants for 24 hour/daily readings. These readings indicate that the average emissions of CO, NO2 and SO2 varies with other factors. The readings show that the late evenings (nighttime) to early mornings have low readings obviously due to lesser vehicular movements and activities and this time range falls between 11pm to 5am. The higher concentrations are more in the mornings through afternoon to early evenings when students and workers are on the move to work and school thus increasing density vehicular activities and movement. It is slightly lower at about 12noon to 2pm owing to the less presence of workers and students from school and work. But the general economic activities that are high in these zones leads to increase in pollution levels as shown by the readings. The following charts show a typical daily reading for a warm day that is not very sunny.

Table 2. Recommendations of the World Health Organization

(WHO) The World health report (2002): Reducing risks, promoting healthy life [20]

Table 2 gives the recommendations of the pollutant gases [16]

Pollutant	World health Organization	European Union	United States
Carbon monoxide (CO)	9	9	9
Nitrogen Dioxide (NO_2)	21	21	53
Sulphur Dioxide (SO_2)	50	48	140
Ozone (O_3)	50	60	80

Table 3. AQI value, description and their corresponding concentration value in μg/m^3

Value	Grade	Description	SO2	NO2	CO
0-50	I	Good	50	40	2,000
51-100	II	Moderate	150	80	4,000
101-150	III	Unhealthy for sensitive people	475	180	14,000
151-200	IV	Unhealthy	800	280	24,000
201-300	V	Very unhealthy	1,600	565	36000
301-500	VI	Hazardous	2,620	940	60000

Table 4. Health effect of NO_2 and sources

Nitrogen dioxide (NO2) Health Effects	Nitrogen dioxide (NO2) Sources
Exposure to elevated levels of nitrogen oxides can contribute to respiratory illness, aggravation of asthma in children, and reduced lung growth.25 Nitrogen oxides react with other air pollutants in the atmosphere to form smog	Nitrogen oxides are produced by the combustion of fossil fuels

$$AQI = \frac{data\ measured\ for\ each\ pollutant}{standard}\ x\ 100 \qquad 1.0$$

Table 5 Health effect of CO and sources

Carbon Monoxide (CO) Health effects	Carbon monoxide (CO) Sources
However, exposure to elevated levels of carbon monoxide can adversely affect the functioning of the heart, resulting in cardiac ischaemia, increased hospital admissions, and possibly increased cardiac mortality. When inhaled, CO binds to haemoglobin in red blood cells passing through the lungs, forming carboxyhemoglobin (COHb). Because CO binds to haemoglobin more tightly than oxygen does, CO occupies the sites normally used to bind and carry oxygen from the lungs to the tissues. One mechanism of CO toxicity is that it decreases the oxygen content of arterial blood which reduces peripheral oxygen delivery.	Carbon monoxide is produced by the incomplete combustion of fossil fuels, largely from motor vehicles and other mobile sources.

Table 6 Health effect of SO_2 and sources

Sulphur dioxide (SO_2) Health Effects	Sulphur Dioxide (SO_2) sources
Exposure to sulphur dioxide causes severe problems for people with asthma and is also associated with increased risk of lung cancer and chronic bronchitis. Sulphur dioxide also reacts with other air pollutants in the atmosphere to form particulate matter.	Most Sulphur dioxide emissions are produced by the combustion of fossil fuels containing sulphur, including coal, oil, gasoline, and diesel, as well as coal-fired electricity plants and metal smelters.

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Fig 4 Chart of typical daily variation of Nitrogen Dioxide

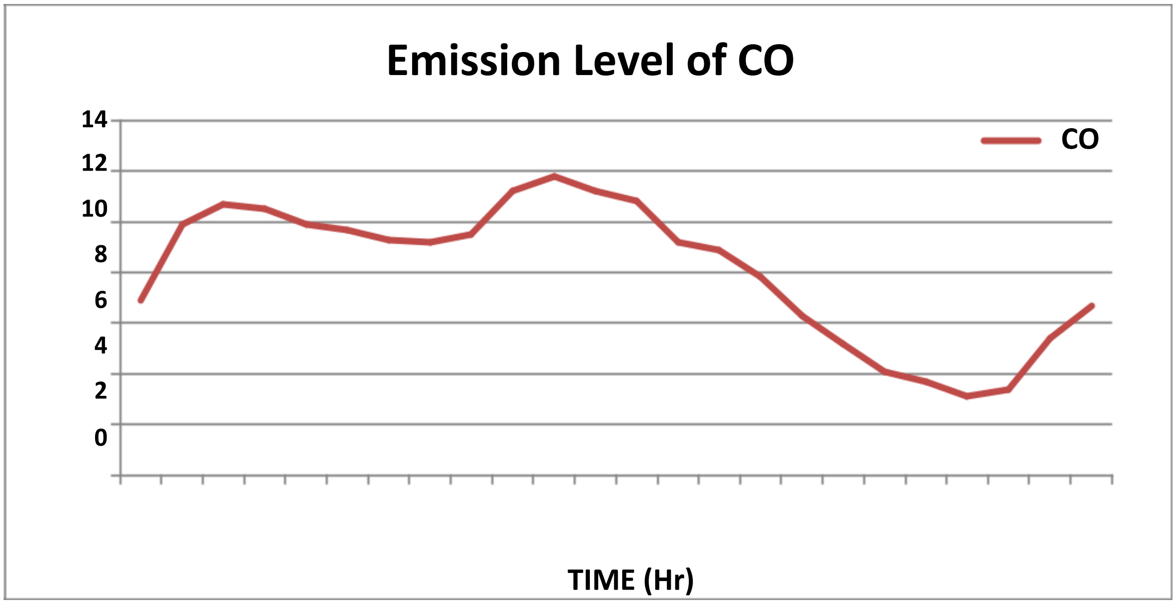
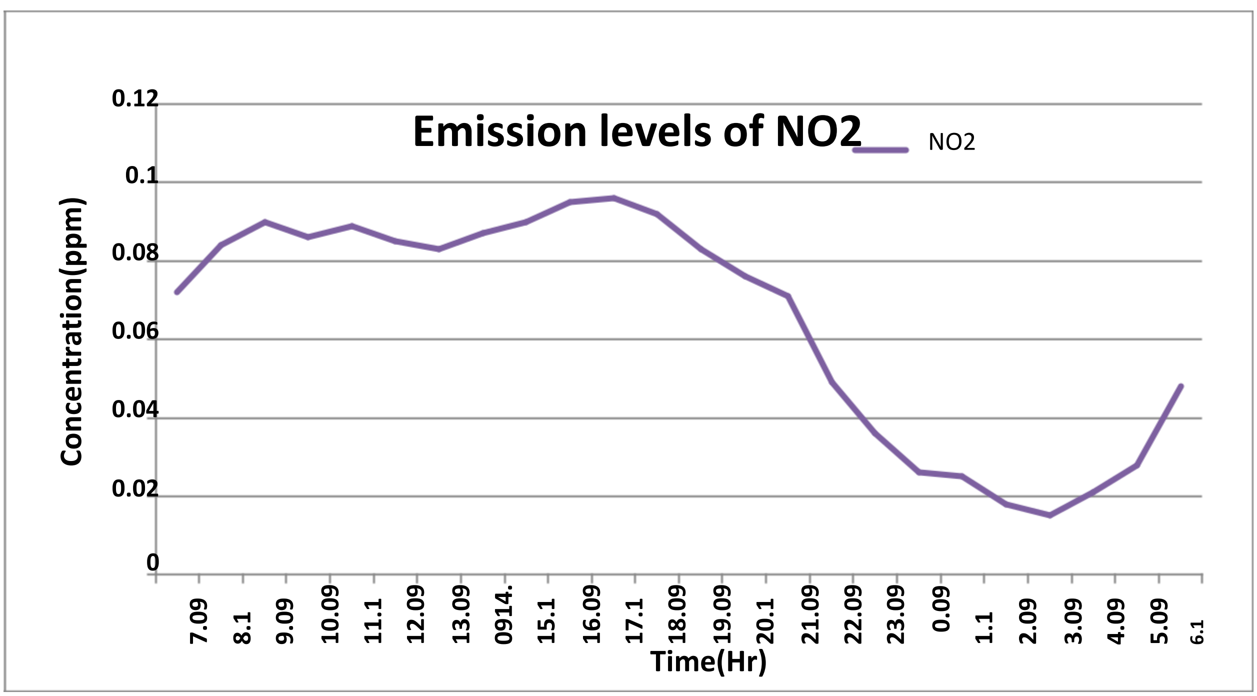


Fig 3. Chart of typical daily variation of carbon monoxide

The daily variations of carbon monoxide as seen from the chart shows a similar pattern observed daily throughout the year. It shows that in the morning to early evening hours the CO levels are high and above WHO and FEPA levels of 10ppm and the high peaks always fall in the morning hours of 8 - 10am and about 4 – 6pm in the eveninghours



The chart for NO2 shows that the average exceeds WHO and FEPA limit of 0.06ppm slightly for a 24hour period. The readings also show strong NO2 presence during the morning hours to evening hours when vehicular activities are intense.

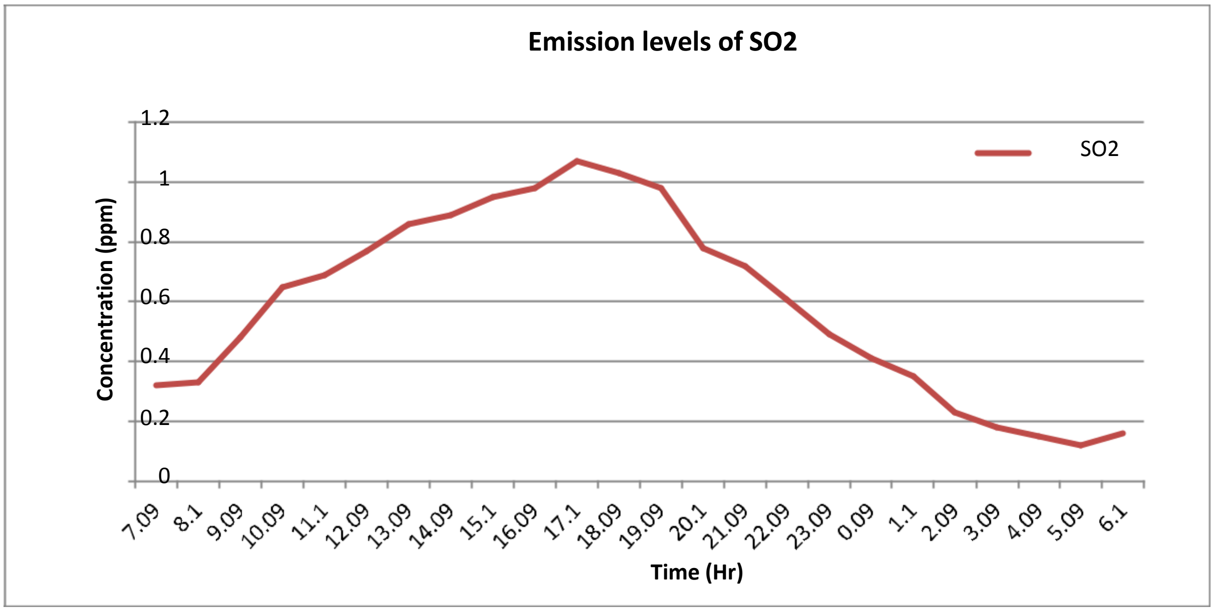


Fig 5 Chart of typical daily variation of Sulphur Dioxide

The Sulphur dioxide chart shows also that the level is high from the morning to the evening hours due to the vehicular activities and peaks more during early evenings.

5. CONCLUSION

In this paper, a wireless gas sensor network focusing on the study of air quality was presented.

The aim was to implement a system of wireless sensor Networks to measure air pollutant of a Nigerian Industrial city using Lagos state as a case study. It would show the pollutants profile at the end of the work for the specified period. The system will be equipped with RF communication link for remote site monitoring and measurement with a remote base station with database for datalogging function with time and date.

The data collated over time would be used for modeling of the environmental pollution pattern of different pollutants at the chosen locations.

This would help to establish relationships between gas pollutant concentrations and human activities in these locations. This would be of great public health significance to the people of Lagos state, thereby reducing the disease burden of mortality and morbidity. This technology will make inroads into the lives of citizens and also that of businesses and organizations, this penetration will also increase in scope and depth due to IoT and other emerging technologies. Not only will new application fields be opened up (real-time remote air pollution monitoring; monitoring interest groups, health risk assessment; etc.), but also the penetration of processes and actions by information and communication technologies (ICT) will increase.

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