Full Research Paper

Real-Time Nitrogen Dioxide Pollutant Monitoring In Lagos State, Nigeria Using Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Networks (WSNs) find its application in various facets of life. Atmospheric contamination in the various elements of air leading to hazardous effects of global warming and acid rains can affect the well-being of a population. An air pollution monitoring system is therefore important to keep away from such adverse imbalance in nature. In the proposed paper, an attempt is made to develop a real time pollution monitoring using wireless sensor networks (WSN). This WSN will monitor the profile concentration of nitrogen dioxide (NO2) in a chosen location. With the rapid growth in the industries, which are the main sources of air pollutants, the problem of air pollution is becoming a serious concern for the health of the population. The concentration of one major air pollutant gases Nitrogen dioxide (NO2) from the air is sensed by the gas sensors. The sensor is properly calibrated as per the standard methods and the gas sensor is then incorporated with the wireless sensor motes using hierarchical cluster-based architecture.The node is expected to sense pollutants, convert, and process the magnitude of pollution to equivalent data output which is transmitted to the remote base station. The expected results would show data of the Nitrogen dioxide sensor for each location and graphical results. Research and suggestions have been offered by researchers for two decades and more on the increasing dangers of industrialization, population growth, influx of used vehicles popularly called 'tokunbos' as they pertain to the public health and adverse effects if not properly managed. The test findings of this work still show if the concentration of gaseous air pollutant like NO2 in a chosen location and at a particular time poses a problem to humans and the environment.

Keywords— Air pollution, Wireless sensor networks, Nitrogen dioxide, Environmental risk, public health, Hierarchical cluster-based architecture

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I. INTRODUCTION

Wireless Sensor Network (WSN is a fast-evolving technology area that is gaining importance due to its various applications. It is an intense wireless network of small, low-priced detectors, which collect and distribute environmental data. With the use of WSNs, supervision and control of physical environments from remote locations can be acted with improved accuracies and timeliness [1]. Air pollution is a serious global problem because it presents a major environmental risk to health of a population. This problem is compounded by the rapid growth of urban population, industrial development, and the increase of the transportation activities [2]. The main cause of air pollution is the burning of fossil fuels. Meanwhile, the consumption of fossil fuels continues to outweigh the use of more environmentally friendly forms of energy. This condition inadvertently has had a major effect on air quality [3].

Transportation of motor vehicles is the main source of air pollution in urban areas. Emissions generated by motorized vehicle activities in urban areas were mainly $NO2$ gas originating from the combustion process [4],[5]. The impact of the use of fossil fuels clearly will reduce air quality. Furthermore, declining air quality will cause serious impacts on human health. According to [6], air pollution is an important risk factor that can lead to mortality and morbidities. It was estimated that half of the deaths that occurred were caused by heart disease, stroke and lung cancer which could be attributed to air pollution. The exposure to air pollution from both outdoor and household (indoor) resulted in the deaths of around 7 million people annually in all regions of the world, while Western Pacific and Southeast Asia were the most affected [6]. WHO estimated that there were 200 thousand deaths due to outdoor pollution that mainly occur in urban areas, where about 93% of cases occurred in developing countries [7].

Air pollutants could come from anthropogenic activities including industry, transportation, offices, and housing, but could also originated from natural activities. The transportation and industrial sectors were the highest contributors to the declining of air quality. It has been predicted that air pollution due to transportation and industrial activities will increase 10-fold in 2020 compared to the conditions in 1990 [8]. Instruments usually used for atmosphere pollution monitoring are Fourier Transform Infrared (FTIR), mass spectrometers and gas chromatographs which give precise and selective gas readings. Because of the bulk size of the instruments, there is high cost of maintenance for a larger scale monitoring application [9].

Gas sensors are becoming equally effective alternative [10] as they are low cost, compact and robust with versatile applications. Gas sensor monitoring methods are basically electrochemical, catalytic bead, photo ionization, infrared and solid-state [9]. Present monitoring methods mainly employ smart transducer interface module (STIM) with semiconductor gas sensors. Geosensor network with control action for monitoring [11] are also unfavorable due to high cost. In this paper, an attempt is made to propose and design a system which is economical, consistent, precise and scalable for the real-time pollution monitoring in an industrial city like Lagos using with WSN. Hierarchical cluster-based architecture is best suited for habitat and environmental monitoring applications with its routing schemes. A hierarchical topology was adopted for this work because a wide geographical coverage area is part of the goal of the WSN design.

2.HIERARCHICAL CLUSTER-BASED ARCHITECTURE

Hierarchical cluster-based architecture is best suited for habitat and environmental monitoring applications with its routing schemes. Hierarchical cluster-based routing schemes are based on the fact that the energy consumed to send a message to a distant node is far greater than the energy needed for a short-range transmission and that this will contribute longer lifespan [12]. In the hierarchical model adopted in this work, sensor nodes are aggregated to form clusters based on their power levels and proximity. Each cluster has a cluster head also called coordinator in this context, has the task of acquiring data of the sensor nodes in its cluster. In other words, a zone could have several clusters and each cluster have a cluster head or coordinator and each coordinator has some sensor nodes. This kind of setup aid in scalability of WSNs [12].

This type of WSN architecture tagged a 3-level hierarchical cluster-based network. It is very useful for regionally managing sensor networks. When a user's query is disseminated to the network through the sensor gateway and the sink node, the responses received from the correspondent sensor nodes are first aggregated to the coordinators, and then each area coordinator aggregates the response data from the cluster heads in the area, finally all the areas having the response data send the aggregated result to the gateway through the sink node. Accordingly, the gateway can acquire the regional sensing data corresponding to the user query from each area node [12].

The hierarchy network system based on the use of clusters was adopted based on the advantages it offers in terms of energy efficiency, coverage distance. The entire network was set up to employ a three-layered hierarchy cluster-based design which is gateway, clusters head and sensor nodes. One of the nodes of a cluster was selected as the cluster-head referred to as coordinator, which acts as the gateway of that cluster to the main network, and it is responsible for acquiring data of the sensor nodes in its cluster. The clusters can only communicate with their cluster heads or coordinators like in a star topology [12].

The cluster-heads and the gateways are setup in mesh topologies as they may communicate with other coordinators (of other clusters) or may directly transmit data to a particular gateway. The coordinators were setup to perform most of the data collection, aggregation and processing to minimize the redundancy of the information collected by the sensor nodes of the cluster leaving the gateways to serve as gateways to the sink which is the base station. A zone consists of gateway and several cluster heads. That is, the entire sensor network has some zones, a zone has some clusters with cluster heads, and a cluster head has some sensor nodes. This kind of structure, i.e., a 3-level hierarchical cluster-based network, is very useful to regionally manage the sensor network.

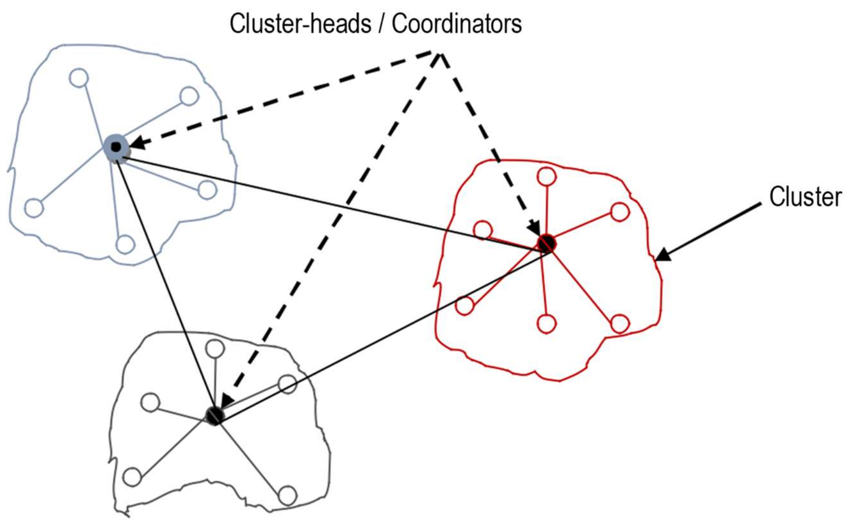

Fig 1. Sensor Nodes organized into clusters with cluster-heads acting as gateway for the nodes that belong to their cluster

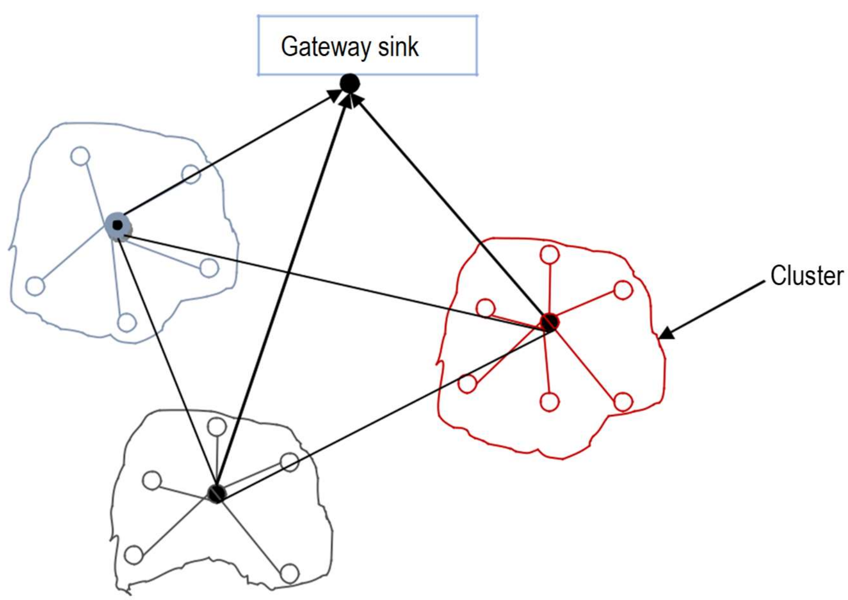

Fig 2. Example of a network with LEACH

The cluster-heads receive data from the nodes of their clusters, and after being processed, the data are transmitted by the cluster-heads directly to the gateway-sink.

3. 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 [13]. 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 [14,15,16].

Fig 3. Map of the Ikeja industrial Estate Study Area

The study area as shown on the Google map has a total area of 7.52km2 (2.51 mi2) 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.

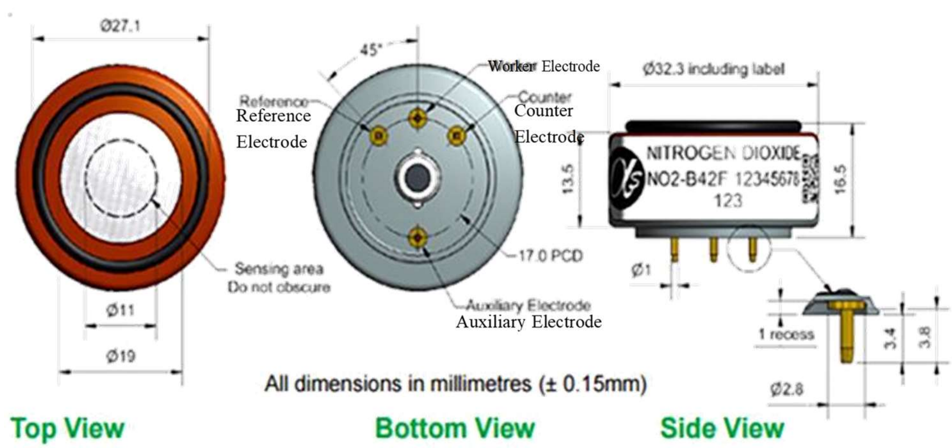

Fig 4. Different views of the Nitrogen Dioxide sensor

4. NITROGEN DIOXIDE SENSOR

The Alphasense NO2-B42F sensor is used to measure ambient NO2 in many low-cost air quality settings. The Alphasense B4 electrochemical gas sensing series used employs a four-electrode approach. The electrodes are embedded in an electrolyte solution separated from the atmosphere by a semi-permeable membrane. The gas of interest diffuses through the membrane into the electrolyte where it contacts a "working" electrode and is either oxidized (in the case of NO and CO) or reduced (NO2 and O3).

The potential at the working electrode is maintained at a constant value with respect to a "reference" electrode. Electric charge produced at the working electrode is balanced by the complementary redox reaction at a "counter" electrode, generating an electric current. The sensor also contains an "auxiliary" electrode, which shares the working electrode's catalyst structure, but is isolated from the ambient environment, accounting for fluctuations in the background current associated with other processes at the electrode and electrolyte. Subtracting the auxiliary current from the working current gives a corrected current dependent on the gas concentration [17]. The humidity dependence is included in the temperature dependence, as there is no evidence for independent humidity dependence and relative humidity exhibits an anti-correlation with temperature in the field.

NO2-B42F Nitrogen Dioxide Sensor Specifications:

(1) Range(ppm): 0~20
(2) Sensitivity: -160~320 nA/ppm at 2ppm NO2
(3) Response time: t90 <70(s) from zero to 2ppm NO2
(4) Zero current: -25~50nA in zero air at 20°C
(5) Operating life: > 2years
(6) Size(mm): Φ32.0×16.5(mm)
(7) Linearity: linear at zero and 5ppm NO2; < ± 1ppb error at full scale

(8) Over gas limit: 50ppm
(9) Pressure range: 80~120kPa
(10) Weight: < 13g
(11) Temperature range: -30~40℃
(12) Humidity range: 15~85%RH
(13) Load resistor: 33~100 Ω

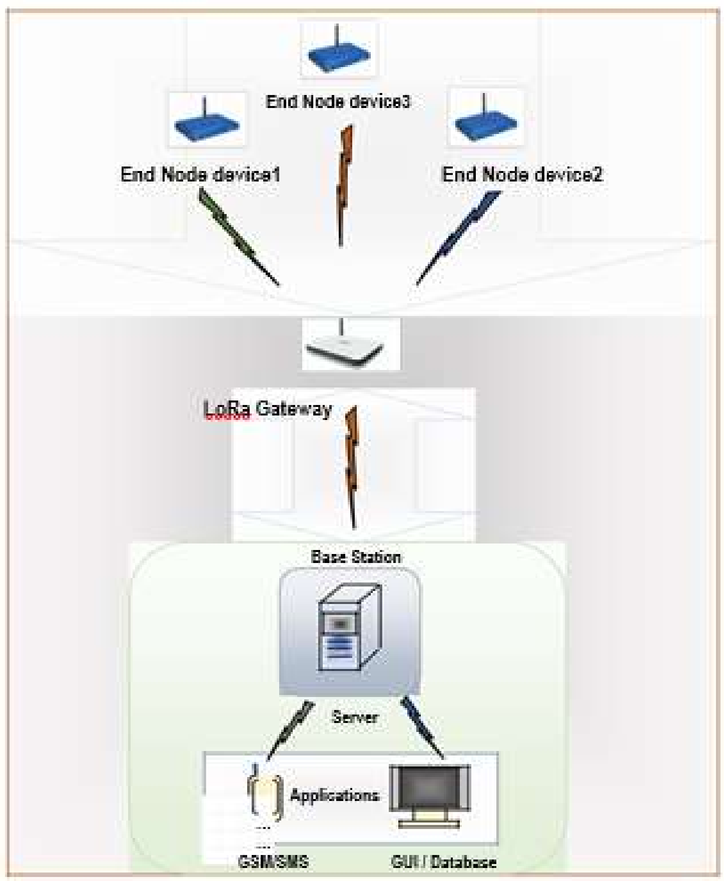

Fig 5. Wireless Sensor Network (WSN) based Air Pollution and Reporting System Architecture

5.WSN BASED NO2 POLLUTION MONITORING AND REPORTING SYSTEM ARCHITECTURE

Fig.5 depicts the wireless sensor network (WSN) application in air pollution monitoring and reporting architecture and concept as embarked on this study. It shows the node of the sensor and a gateway. 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 has is serving 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 (WSN) sensor nodes, sensor locations, time, and date of transmissions for data reception.

The major functional blocks of the system are listed as;
1. Sensor Nodes
2. Gateway
3. Remote Base Station (Server)

TABLE 1: RESULTS FOR ZONE 1 FOR A TYPICAL WARM DAY WITH AVERAGE TEMPERATURE OF 28^{oc} AND HUMIDITY OF 65%.

Time	NO2	Temperature	Humidity
7.09	0.072	26	71
8.10	0.084	27	69
9.09	0.09	27	70
10.09	0.086	28	67
11.10	0.089	29	63
12.09	0.085	30	62
13.09	0.083	31	60
14.09	0.087	32	59
15.10	0.090	33	57
16.09	0.095	33	54
17.10	0.096	30	58
18.09	0.092	29	62
19.09	0.083	27	64
20.10	0.076	27	66
21.09	0.071	27	67
22.09	0.049	27	70
23.09	0.036	26	73
0.09	0.026	26	73
1.10	0.025	26	74
2.09	0.018	25	76
3.09	0.015	25	77
4.09	0.021	25	78
5.09	0.028	25	76
6.10	0.046	26	72
Average	0.064	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 every one-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.

Figure 6 shows the variation of NO2 gas pollutants for 24 hour/daily readings. These readings indicate that the average emissions NO2 is relatively higher during peak periods. This is mainly because its main emission sources are of vehicular origin. The readings show that the late evenings (night-time) 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 of 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 still results in high pollution levels as shown by the readings. The following charts show a typical daily reading for a warm day that is not very sunny.

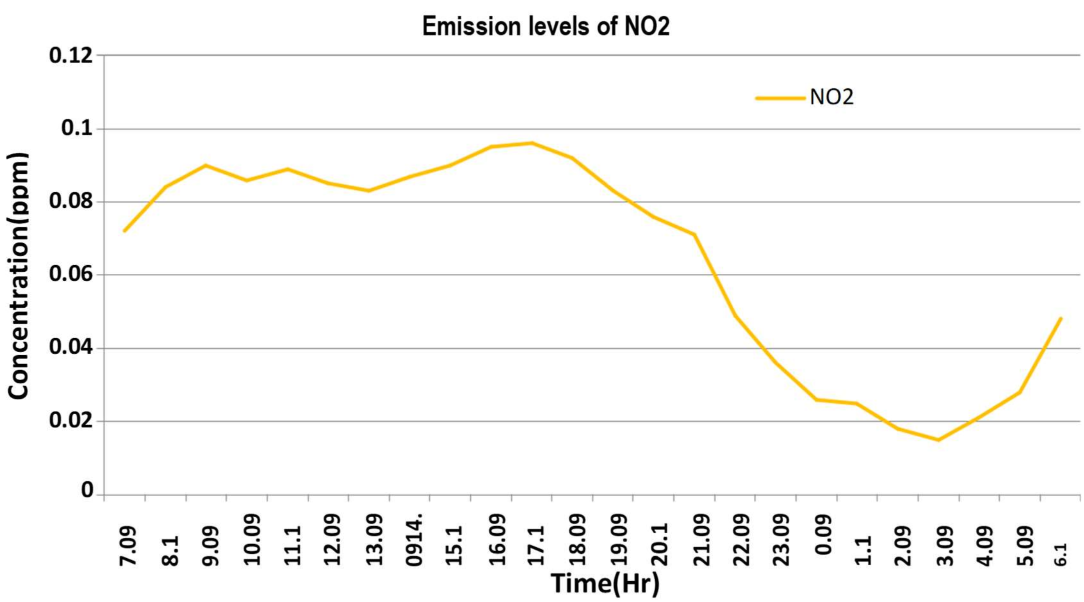

Fig 6. Chart of typical daily variation of Nitrogen Dioxide

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 much.

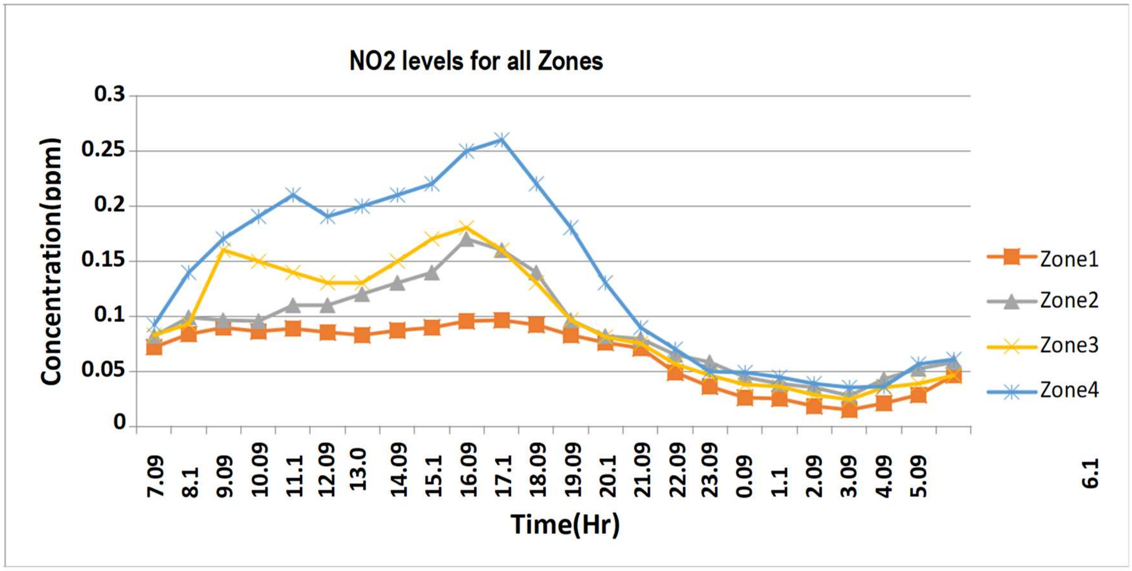

Fig 7. Chart of NO2 emission levels for Zone 1 to Zone 4

Zone 4 shows a significant level of NO2 when compared to other zones. The major source of the concentration levels being high is due to the high vehicular activities, from gasoline and diesel vehicles.

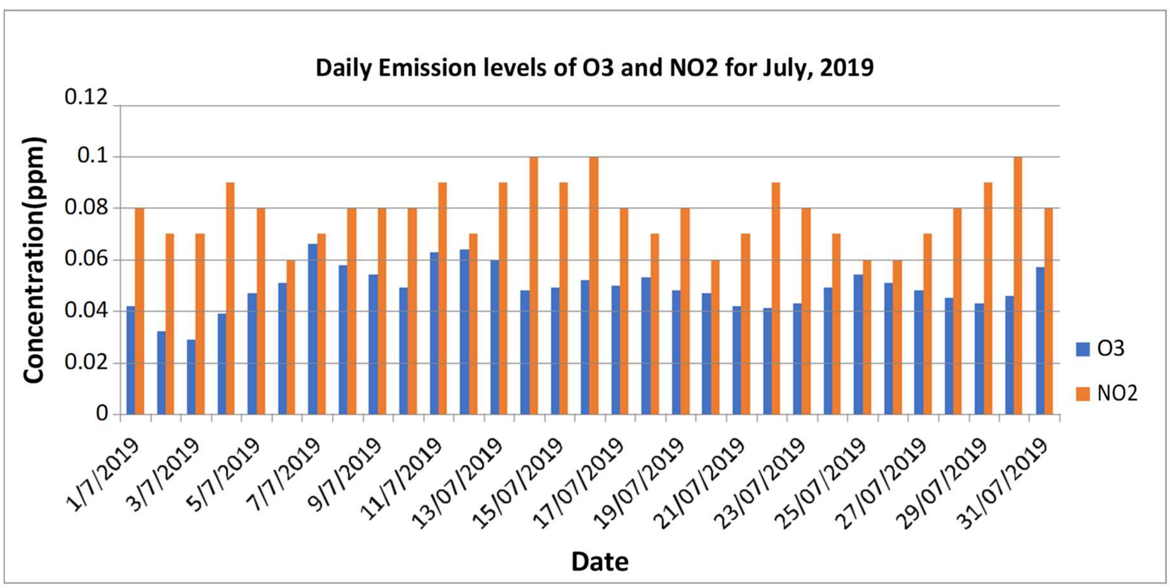

Fig 8: Daily O3 and NO2 emission level

According to recommended standard for O3 is 0.05ppm and 0.06ppm for NO 2 (FEPA & WHO). O3 level is poor as it swings from above and below thresholds and this shows there is potential danger of excess. NO2 exceeds the standard and as such prolong exposure to these levels there is tendency for sensitive individuals to suffer respiratory related illnesses.

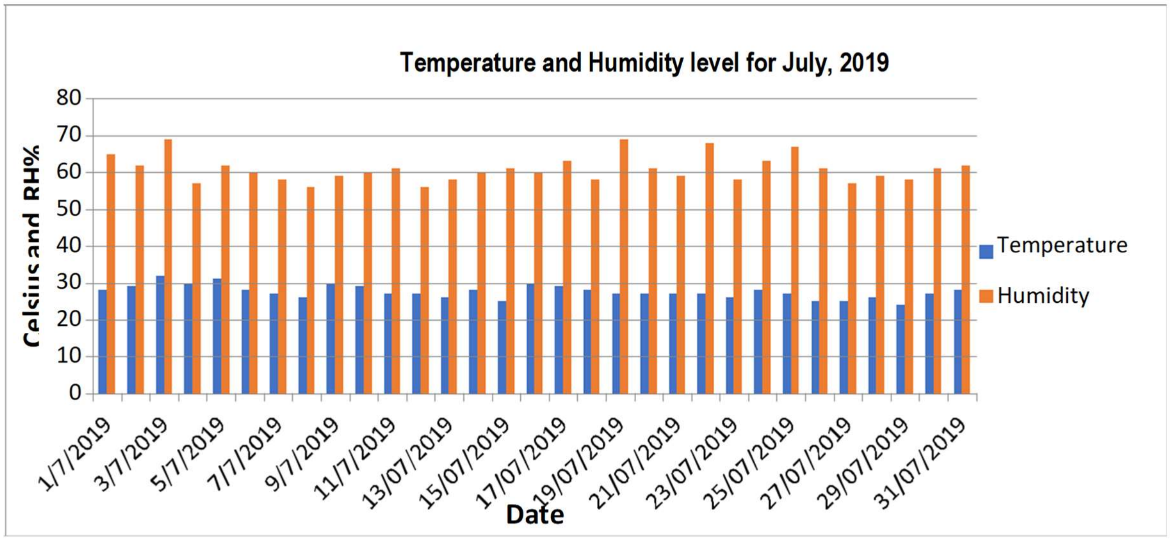

Fig 9. Daily Temperature and Humidity levels

TABLE 2: RESULTS FOR NO2 MONTHLY AVERAGES TREND FOR 2019

Date	NO2	Temperature	Humidity
January	0.078	28	61
February	0.072	29	57
March	0.069	30	53
April	0.068	29	58
May	0.069	29	59
June	0.065	28	60
July	0.061	27	59
August	0.058	27	61
September	0.057	28	60
October	0.059	28	63
November	0.060	29	58
December	0.064	29	60
Yearly			
Average	0.065	28.5	59.1

6. CONCLUSION

A real-time pollutant monitoring system was developed to monitor Nitrogen oxide gas concentration in the chosen area. This was implemented considering its importance and relevance in the present scenario. A detailed study and survey were done in terms of technical viability and economic feasibility in deploying monitoring systems in other industrial areas of the state. Experimentation was carried out at the industrial area of Ikeja, Lagos state and the developed wireless monitoring system was able to collect the air pollutant data consistently under the various conditions and timings.

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