A Survey of Network and Intelligent air pollution monitoring in South Africa

Ntombikayise Koyana
Electrical, Electronic & Computer Engineering Department
Central University of Technology
Freestate, South Africa.
ntombikayise.koyana0@gmail.com

Elisha Didam Markus
Electrical, Electronic & Computer Engineering Department
Central University of Technology
Freestate, South Africa.
emarkus@ieee.org

Adnan M. Abu-Mahfouz
Council for Scientific and Industrial Research (CSIR)
Pretoria, South Africa.
a.abumahfouz@ieee.og

***Abstract* - Air pollution is one of the largest environmental and public health challenges in the world today. It leads to adverse effects on human health, climate and the ecosystem. Many techniques for monitoring air pollution have been applied over the years. This paper discusses a survey of air pollution monitoring and what has been done to alleviate its effects. Various air polluting methods are discussed based on recent literature. A further discussion is included to expose the ills of air pollution and how various studies have sought to solve the problem. A special emphasis on South Africa is considered whereby rising levels of pollution is prevalent due to industrial and traffic radiation. The studies show that South Africa is still faced with a crisis in infrastructure. Furthermore, this research focuses on intelligent air pollution monitoring and deliberates on its applications and benefits.**

Keywords - Air pollution monitoring, Intelligent monitoring, IoTs, LoRa

I. INTRODUCTION

Air pollution is a major environmental issue affecting respiratory health globally. In every major city around the world, air pollution has become a serious matter [1]. As a major fast developing country, South Africa has rising levels of air pollution from industrial and traffic emissions, coupled with natural phenomena dust. High concentrations of air pollution, namely, fine particulate matter (PM [1], has resulted in productivity losses and human mortality. Furthermore, the World Health Organisation (WHO) estimated that a large number of children around the world breathe toxic air. In 2016, the WHO reported that 6 000 children die of acute lower respiratory infections caused by polluted air. Lower respiratory tract infections were the leading cause of undefined death globally and in South Africa [2]. The report further stated that pollution was a leading cause of undefinable mortality, such as strokes, ischaemic heart disease and lung cancer. In addition, Main activity within the North West Province is confined to the main routes and mine industries. These include the Platinum other acute respiratory diseases were associated with air pollution. Air pollutants, Particulate, nitrogen dioxide (NO2), and sulfur dioxide (SO2) has become an important concern as it impacts on human health in many ways, such as chronic obstructive pulmonary diseases [3]. Hence, what we breathe, affects our health. Over the past 20 years, indication for adverse health effects of ambient air pollution has grown dramatically. It is also recognized that the effects on human health are large and widespread. Furthermore, air quality-related deaths in Africa rank within the top leading causes of death in Africa. Results also show that natural sources, in particular, windblown dust emissions, have large impacts on air quality and human health in Africa [5]. Although the ambient particulates were the most widely used pollution index among these studies, the gaseous pollutants such as nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3) and carbon monoxide (CO) also have direct impact on the increased morbidity and mortality rate, hence, the effects of these pollutants have been extensively discussed in the literature [6].

The statistics below gives a summary of the effects of air pollution in South Africa nad globally.

- In 2014, 92% of the worlds population was living in places where the WHO air quality guidelines levels were not met.
- Outdoor air pollution in both cities and rural areas were estimated to cause 3 million premature deaths worldwide in 2012.
- In 2012, it is estimated that 72% of outdoor air pollution-related premature deaths were due to ischaemic heart disease and strokes.
- Indoor smoke is also a serious health risk for some 3 billion people who heat their homes and cook with biomass fuels and coal. 4.3 million premature deaths were attributable to household air pollution in 2012. Almost all of that burden was in low-middle-income countries such as South Africa [4].

Studies show that 90% of mining activity in the North West province occurs in the Rustenburg and Klerksdorp areas [5].

The probable sources of air pollutants are from the mining and metallurgical industries and include wind-blown dust from slimes, landfills, haul roads used by mining and large transport vehicles, and fugitive emissions [7]. This has motivated an evaluation of the air quality with regard to the particulate matter will be undertaken in the areas Kanana and Jouberton at Klerksdorp gold mining town of the North-West province of South Africa. Hence, this explains the need to implement easy low-cost methods to monitor and predict early hazardous symptoms [8]. By design, the system of air pollution using artificial intelligence systems that will assist the public, both industrial and residential is concerned about their well being by taking precautionary steps to preclude impending hazards. South African Air Quality Information system sometimes show the air quality hazard. This is evident in Figure 1 indicating the PM10 frequently exceeded the national ambient air quality standard in Kerksdorp, in the area of Jouberton (refer figure 1) [9].

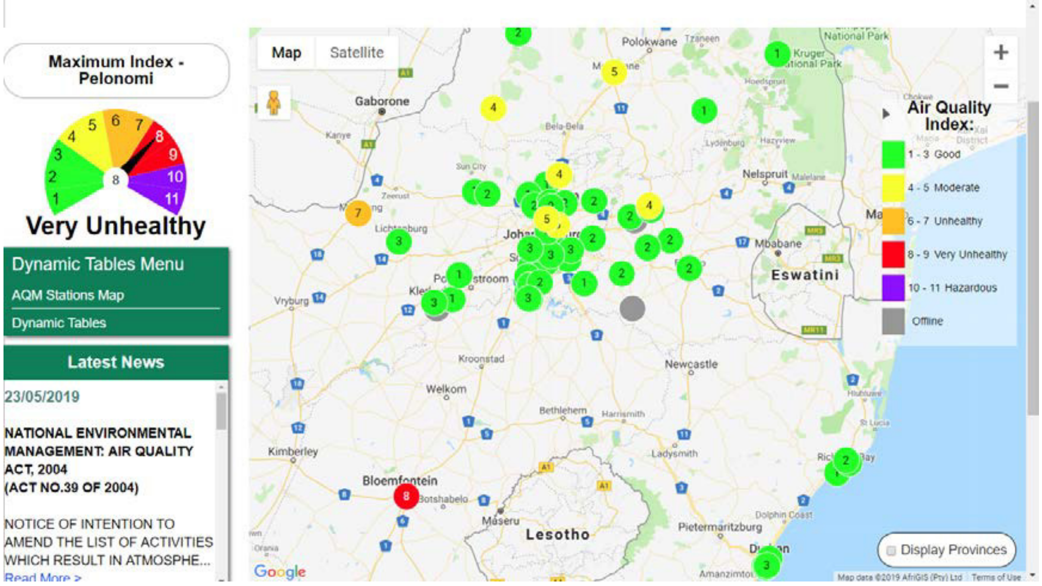

Figure 1: Monitoring graph map

However, due to the substantial cost related to setting up and maintaining such stations, the number of monitoring sites tend to be quite small in most areas, hence by design, the system of air pollution using artificial intelligence systems will assist the public, both industrial and residences. Hence, the problem of pollution has to be addressed to avoid devastating effects on the populace.

II Related work

1. General air pollution monitoring methods

While everyone seems to agree on the severity of the air pollution issue, it is hard to obtain accurate, real-time data on air pollution within the city. This complicates the evidence gathering and input towards the future policy**.** In addition, some studies shows that air pollution in an urban area in South Africa was estimated to cause 3.7% of the national mortality from cardiopulmonary disease and 5.1% of mortality attributable to cancers of the trachea, bronchus, and lung. Air pollution has under-recognized public health impact in South Africa. Fossil fuel combustion emissions and traffic-related air pollution remain key targets for public health in South Africa. The following comparative risk assessment (CRA) methodology developed by the World Health Organisation (WHO) in most urban areas annual mean concentration of Particulate matter (PM) [10]. Also, in another recent study, it is shown that air pollutants is a rapidly developing branch of analytical chemistry aimed at classifying air pollutants and determining their levels which is a long-drawn-out, laborious, and costly process. The study further provides information on devices used in various kinds of mobile laboratories. They reviewed the portable gas chromatographs and handheld devices used for identifying and determining specific harmful substances in air pollutant. Innovative approaches in analytical instrumentation that can be used in air monitoring are presented, as are future trends in the field of mobile air monitoring systems [12]. Other authors have proposed several advanced air pollution monitoring systems for evaluating foremost air pollutants like CO2, CO, O3, SO2 , Particulate matter (PM) with better results [12]. Likewise, Kang et al. intended to develop real-time air quality monitoring and evaluation systems supporting air quality evaluation and analysis on multiple levels. They investigated various big-data and machine learning-based techniques for air quality forecasting [13].

2. Intelligent air pollution monitoring

Several authors have discussed some intelligent techniques for air pollution monitoring. For instance, in [14], the authors proposed the development of Air-Pollution Prediction in Smart Cities through MachineLearning Methods. Their main goal was to analyze different machine learning techniques to predict ozone levels. The aim of their analysis was to obtain the best model for predicting ozone. Whereas in [15], the authors thought of acquainting with high quantity hardware-software substructure to wrinkle information from vehicles and efficient procedure to provide original ITS services. They suggest a parallelization methodology of a fuzzy clustering technique on heterogeneous servers based on CPU and several GPUs, tailored to classification problems. Intelligent Transportation Systems (ITS) pioneer contributions towards the application of information and communication technologies in vehicles to improve safety by means of sensors, actuators, and embedded computers [16]. Further work by Wei et al. 2015 showed the concept of The Next Generation Air Pollution Monitoring System (TNGAPMS) with prominence on the need for industrialized a real-time air pollution monitoring systems with low cost, energy proficient and high spatiotemporal resolve. The Next Generation Air Pollution Monitoring System (TNGAPMS) categorized into three types of sensor networks based upon the transporters of the sensing elements are Sensors static Sensor Network (SSN), Community Sensor Network (CSN), Vehicle Sensor Networks (VSN). In all of these classifications it was confirmed that an air pollution monitoring system with high spatiotemporal resolution, cost, and energy efficiency, deployment and maintenance achievability, suitable accessing ability for the public or professional users are feasible [17]. Therefore, Jenab proposes a fuzzy Bayesian air quality monitoring model that is able to mimic human-like intelligent behavior in the environmental analysis. Fuzzy intelligent air quality model has been developed which uses airborne particle density signals of workstations in order to determine whether the air quality is in a normal or abnormal condition. The model is based on a fuzzy Bayesian that is promisingly able to classify the status of air quality [18]. Guanochanga presents the design and implementation of a secure and low-cost real-time air pollution monitoring system. In such sense, a three-layer architecture system was implemented. The first layer contains sensors connected to an Arduino platform towards the data processing node (Raspberry's Pi), which through a wireless network sends messages, using the Message Queuing Telemetry Transport (MQTT) protocol. Furthermore, a WEB service was shared in order to transmit the information for posterior analysis. The client layer can be accessed from a Web browser, a PC or smartphone. The results demonstrate that the proposed message architecture is able to translate JSON strings sent by the Arduino-based sensor Nodes and the Raspberry Pi gateway node, information about several types of air contaminants have been effectively visualized using web services [19]. Furthermore, Genikomsakis presents the on-field testing of the proposed low-cost air pollution monitoring system (APMS) implementation using roadside measurements from a mobile laboratory equipped with a calibrated instrument as the basis of comparison and showcases its accuracy on characterizing the PM2.5 concentrations on 1 min resolution in an on-road trial. Presenting a case study of this paper highlights the necessity of collecting high-resolution geolocation data of PM2.5 concentrations in an urban setting by comparing the measurements collected by the low-cost APMS mounted on an e-bike with those retrieved from the local fixed monitoring station in Mons [20].

3. Air pollution using IoTs

Doni et al. proposed establishing multi-sensor air quality monitoring using IoTs. Collected works reveal that manual data computation using the laboratory methods is time-consuming and existing systems are inefficient at providing accurate results. Furthermore, they do not provide long-range communication, but since this project uses GPRS module the data can be transmitted over a very long range [21]. However, Kumar [22] presented a real-time individual air quality monitoring system which embraces several constraints: PM 2.5, carbon monoxide, carbon dioxide, and air pressure. Internet of Things (IoTs) now plays a deep fundamental role in air quality monitoring systems. IoTs converging with cloud computing proposes a unique technique used for superior controlling of data coming from different sensors, collected and transmitted by low power, low-cost ARM-based minicomputer Raspberry p [22]i. Also, Parmar et al. proposed an IoT based low-cost air pollution monitoring system [23]. In addition, Chen [24] discusses IoTs based air pollution monitoring and forecasting system. They commanded that by using IoT, hardware cost may be reduced up to 1/10 as of tenth of initial cost. Hence, Souvik and Voguish in their paper explored the well-thought-out monitoring air pollution on roads and track vehicles. They proposed the use of IoTs to address this problem [25].

In providing an overview of the most relevant IoT architectures and protocols for air monitoring, crowdsensing has been presented as an authoritative key to address environmental monitoring, allowing to control air pollution levels in congested urban areas which circulated, collective, low-cost inaccurate manner [26]. Hence, Safia distributed energy-efficient algorithm, called the Hilbert-order Collection Strategy (HCS), which uses a mobile sink (e.g., drone) to collect data from a mobile wireless sensor network (WSN) and detect environmental phenomena. By addressing the problem of detecting phenomena such as air pollution, in the IoT environment [27], Miles et al. suggests a decision support system (DSS) to permit the analysis of diverse justification strategies to reduce pollution. Hence, an advanced model that could be used to assess justification strategies and the consequence that they could have on reducing critical atmospheric pollution levels, refining the environment of urban, surroundings and justifying hypothetically hazardous areas by monitoring air quality with IoT and combining data consumed from multiple heterogeneous data sources [28]. A much denser sensor network is required, which is directly able to monitor air pollution values and analysis of air pollution can be achieved.

Particularly Low-Power Wide-Area Networks (LPWAN) such as LoRa, Sigfox or NB-IoT enable smart sensing of wide areas with low power consumption [29]. Likewise, Liu et al. recommend a scheme for air pollution monitoring using wireless sensor networks. At this juncture, the sensors are deployed in the environment to continuously monitor the air quality. These sensors are integrated with CO sensors. The communication among the sensors takes place with the help of the ZigBee protocol. Control centered performs the task of collecting the data from the servers and alerts the users by sending SMS. MySQL is used for the collection and storage of data [30]. Rushikesh introduces a monitoring system using the Internet of Things (IoT) which is capable of detecting vehicles causing pollution on the city roads and measures various types of pollutants, and its level in the air. The paper reports on the status of air quality whenever needed to the environmental agencies [31]. Luo demonstrates such issues by using a.com, a popular low-cost air quality monitoring system that provides an affordable and continuous air quality monitoring capability to broad communities. To protect the air quality monitoring network under this investigation, we denote the company of interest as a.com [32]. Balasubramaniyan's (2016) study reveals the usage of Single Board Computers for the integration of IoTs with WSN for Air Quality Monitoring System (AQMS), where Single Board Computers are accomplished of performing even complex tasks with enriched speed and summary convolution. The integration of cloud services with Single Board Computers makes alerting process smart and real-time [33].

Kumar et al. suggested a model to deploy the IoTs devices to measure air pollution level in a specified region by putting into practice of a Wi-Fi constructed plug and sensing device for devoted air pollution monitoring using IoTs. Air pollution monitoring system, being one submission of IoTs that necessitates devices to be arranged in several localities, requires suitable placement of the devices (nodes) and all-region is segregated into grids and for each grid is allocated in a priority. The outcomes show that a planned deployment based on priority optimizes the number of devices to be deployed, thereby minimizing the cost of deployment [34].

Mahajan et al. included IoT technology and imitation brainpower to come up with a PM2.5 forecast system. They designed a forecasting model using exponential leveling which performs hourly PM2.5 forecast based on real-time data acquired from the IoT devices deployed all over Taiwan. Parameters such as mean error, accuracy and computation time were used to analyze the results. To evaluate, the model was tested on 132 monitoring stations. The method was to be developed which uses exponential smoothing with drift. Experiments and evaluation were performed using the real-time PM2.5 data obtained from large scale deployment of IoT devices [35].

Although Saha et al's main objective was to find the pollutants in nature with the help of the IoTs by developing observance devices to keep track of air pollution, they decided to use Raspberry Pi and some sensors for this project which permits the administrator to watch and control the desired parameters within the network [36]. The IoTs objective was to facilitate conservative sensing devices to interconnect with other devices and to supportively provide intelligent service. For instance, IoT can be used to monitor air quality in a city to provide real-time information and admonitions to occupants as well as to control air pollution [37] [38].

4. Lora based air pollution monitoring

Latre et al indicated that there are currently a plethora of wireless technologies available to connect the city sensors and actuators to the Internet (e.g., LoRa, WiFi, ZigBee). Each technology comes with its own set of strengths and weaknesses in terms of range, data rates, and energy consumption. It allows the setup and validation of new smart city experiments both at a technology and user level. City of Things consists of a multi-wireless technology network infrastructure, the capacity to easily perform data experiments on top and a living lab approach to validate and other features the experiments [39]. In addition, it will compare commonly IoT communication protocols, with an emphasis on the main features and behaviors of various metrics of power consumption security spreading data rate. The advantage of using this method is that the offset in time and frequency to the sender and receiver is the same, thus considerably reducing the complexity of the receiver.

Some advantages of LoRaWAN technology are:

- Uses the unlicensed ISM frequency band
- It is scalable
- It supports bi-directional communication
- Provides a high level of security due to encryption algorithms
- Provides energy efficiency

Some authors have projected a system that can be laid out in a large number in the monitoring area to form sensor network. The used range tests at an outdoor area show that LoRa is able to reach to long distances, approximately up to 50Km and TX power is only about (30-110)mA which is lower compared with other used wireless technology. Also, a LoRa modem is used for wireless communication with the features such as low cost, long-distance, high coverage, long device battery life [40-42]. Lee and Ke proposed the LoRa mesh networking system and achieved an average 88.49% packet delivery ratio, whereas the star-network topology used by LoRa achieved only 58.7% under the same settings [43].

Table 1: Comparison of various communication protocols

Characteristics	Bluetooth	Zigbee	LPWAN(LoRa)
Frequency band	2.4 GHz	2.4 MHz	Sub-GHz ISM band
Data Rate	1 Mps	250kps	27kps
Rage	Short-range (10-30)m	Short-range (10-100)m	Long range (10-50)km
Topology	Star-bus network	Star; Mesh, Cluster	Star
Modulation Type	GFSK	BPSK/ O-QPSK	FSK – CSS
Power Comsumption	12.5mA	40mA	30mA

Hence the LoRaWAN technology in the field of IoT and especially in sensor network solutions has proven to be useful. Therefore there is need of re-accessing stationary monitoring stations with the full set of pollutants monitoring versus the use pollutant specific in this station and passive sampling to provide information on areas with high pollution levels by using the IoT monitoring systems with low cost and significance area monitoring data to analyse and report on long term trends in the province.

III Discussion

The research methodology is a literature survey and primary articles were selected by means of a systematic literature review. Table 1 gives a summary of the analysis of the review. Various communication networks used for pollution monitoring are highlighted and how pollution was alleviated. It is clear from the study that intelligent monitoring of air pollution is still at its inception especially in South Africa.

Table 2: Summary of Key Findings

Ref.	Pollutants Parameters	Network Communication	Air Pollution Monitoring Technique	Pollution alleviation	Gap
[9]	NO2, CO	WSN	Real-time and log data to a remote server	Monitoring system that constantly keeps track of air quality in an area	Less accurate data is generated
[29]	PM2.5, PM10, ozone (O3), NO2, SO2 and CO.	WSN, LPWAN	Low-Power Wide-Area technologies as building block for smart sensor in air quality measurements	Much denser sensor network is used to directly monitor air pollution values	Developed sensors are not miniaturizable, energy efficient and accurate enough to create useful information
[31]	NO2, CO2, SO2	Wireless sensor network (WSN)	Vehicular IOT Based	The vehicle user is warned of the extent of pollution from his vehicle. Hence, is able to control emissions	No appropriate measure taken for air pollution
[35]	CO, PM(2.5, 10), NO2	Zig-Bee	Monitoring data from the stationary nodes deployed in the city to the mobile nodes on Public Transport buses and cars connected through IoT technology	Impact on the city pollution control because when it is possible to monitor precisely, it is also possible to prevent pollution	Better communication mechanism is required between coordinator nodes for more accurate results
[36]	CO2, NO2 and SO2	GSM	An air quality monitoring system based on IoT architecture for ambient assist environments	System gives a viable indoor air quality evaluation in order to anticipate technical nterventions for improving indoor air quality	The security of data transmission and authentication process needs to be improved
[44]	CO2, CO and HS4	GPS	Android application termed IoT-Mobair so that users can access relevant air quality data from the cloud	Detect, monitor, and test air pollution in a given area. Warning is displayed if the pollution level is too high	Signals may be lost where licenced band signals are lost
[45]	CO2, NO2 and SO2	Zig-Bee	Hierarchical air quality monitoring system based on IOT technology	Analyses real-time information through IOT and collected from the sensors, stores all information to the database	Automobile emission is the biggest factor which contributes to the air pollution
[46]	CO2, NO2, SO2	LPWAN	Air pollution monitoring system using LoRa as transceiver system	Prevents the level of air pollution from getting worse	Low cost, it is based on Internet of things, so remote access is possible
[47]	PM-10	Wireless sensor network (WSN)	Integrated pollution monitoring system	Government and policy makers as basic information to take further actions reducing pollution level	N/A
[48]	NO2	Neural networks	Data-driven Mobile air pollution monitoring	Data generated by the mobile sensing units when used outdoors are accurately used to predict future NO2 levels in urban areas	Data accuracy is compromised
[49]	CH_4, NO_2, H_2S	Intelligent DSS with distributed WSN	Autonomous remote monitoring framework	Remote pollution monitoring in the mines is satisfactory. It is also done in real-time	Challenge of of detecting sensor nodes and noise
[50]	NO_x, H_2S, CO_2	ANFIS	Using meterelogical factors to predict ozone concentration levels	Ozone level components are adequately estimated and assessed	N/A
[51]	SO_2, NO_x, O_3 NH_3, CO, PM10	Machinelearning;RF , DT, KNN	Using data analysis and prediction	Predicting pollution variables enables mitigation activities to be initiated	Prediction is not 100% accurate, hence there is room for improvement
[52]	NO_x, CO_x	Intelligent transport system using fuzzy technique	Cooperative intelligent transportation systems using V2I communication	Pollution system correctly identifies highly polluting traffic areas and drivers	Hardware features included may require different run-time strategies

IV. Conclusion

In this study, the state of air pollution monitoring, especially in South Africa has been presented. Globally, other countries have introduced the use of various technologies in order to obtain data for efficient monitoring and alleviation procedures, while others have suggested the need for industrialised real-time air pollution monitoring. The studies show that South Africa is still faced with crisis in infrastructure. This paper has discussed a survey on air pollution monitoring and what has been done to alleviate its effects. Furthermore, intelligent air pollution monitoring where machine learning techniqies has been used is not popular in South Africa. It is clear from the literature studied that intelligent methods of air pollution monitoring offer better results, especially because they are able to predict pollution in cases where sensors may fail. Currently the monitoring systems in South Africa need to be revamped to cater for such eventualities. Furthermore, the cost of sensors has improved in recent years. This implies that air pollution monitoring can be achieved in local settings with low costs, thereby improving the livelihood of society. The demand for real-time monitoring by implementation of an intelligent solution is therefore on the rise globally. This implies that research in this direction will gain much more attention in the near future. Furthermore, the implementation of low cost IoT end-to-end systems like LoRa will be a driving force towards such deployments.

IV REFERENCES

[1] Altieri, K. and Keen, S. 2016. The cost of air pollution in South Africa. International Growth Centre Blog.

[2] http://www.heartfoundation.co.za. (2017). AIR POLLUTION. [online] Available at http://www.heartfoundation.co.za/pollution accessed [Accessed 29 March 2017].

[3] Ghozikali, M.G., Mosaferi, M., Safari, G.H. and Jaafari, J. 2015. Effect of exposure to O3, NO2, and SO2 on chronic obstructive pulmonary disease hospitalizations in Tabriz, Iran. *Environmental Science and Pollution Research*, 22(4), pp.2817-2823.

[4] West, J.J., Cohen, A., Dentener, F., Brunekreef, B., Zhu, T., Armstrong, B., Bell, M.L., Brauer, M., Carmichael, G., Costa, D.L. and Dockery, D.W. 2016. What we breathe impacts our health: improving understanding of the link between air pollution and health.

[5] Bauer, Susanne E., et al. "Desert Dust, Industrialization, and Agricultural Fires: Health Impacts of Outdoor Air Pollution in Africa." Journal of Geophysical Research: Atmospheres 124.7 (2019): 4104-4120.

[6] Boyce, C.P., Goodman, J.E., Sax, S.N. and Loftus, C.T. 2015. Providing perspective for interpreting cardiovascular mortality risks associated with ozone exposures. *Regulatory Toxicology and Pharmacology,* 72(1), pp.107-116.

[7] Khaniabadi, Y.O., Goudarzi, G., Daryanoosh, S.M., Borgini, A., Tittarelli, A. and De Marco, A. 2017. Exposure to PM 10, NO 2, and O 3 and impacts on human health. *Environmental science and pollution research,* 24(3), pp.2781-2789.

[8] Cer.org.za. (2019). [online] Available at: https://cer.org.za/wp-content/uploads/2010/03/North-West-Environmental-Implementation-Plan.pdf [Accessed 8 April. 2019].

[9] Kumar, P., Morawska, L., Martani, C., Biskos, G., Neophytou, M., Di Sabatino, S., Bell, M., Norford, L. and Britter, R. 2015. The rise of low-cost sensing for managing air pollution in cities. *Environment International,* 75, pp.199-205.

[10] Norman, R., Cairncross, E., Witi, J., Bradshaw, D. and Collaboration, S.A.C.R.A. 2007. Estimating the burden of disease attributable to urban outdoor air pollution in South Africa in 2000. *South African Medical Journal,* 97(8), pp.782-790.

[11] Marć, M., Tobiszewski, M., Zabiegała, B., de la Guardia, M. and Namieśnik, J. 2015. Current air quality analytics and monitoring: A review. *Analytica Chimica Acta,* 853, pp.116-126.

[12] Pavani, M. and Rao, P.T. 2017. Urban air pollution monitoring using wireless sensor networks: a comprehensive review. *International Journal of Communication Networks and Information Security,* 9(3), pp.439-449.

[13] Kang, G.K., Gao, J.Z., Chiao, S., Lu, S. and Xie, G. 2018. Air quality prediction: Big data and machine learning approaches, *International Journal of Environmental Science and Development,* 9(1), pp.8-16

[14] Martínez-España, R., Bueno-Crespo, A., Timon-Perez, I.M., Soto, J., Muñoz, A. and Cecilia, J.M. 2018. Air-Pollution Prediction in Smart Cities through Machine Learning Methods: A Case of Study in Murcia, Spain. J. UCS, 24(3), pp.261-276.

[16] Cecilia, J.M., Timón, I., Soto, J., Santa, J., Pereñíguez, F. and Muñoz, A., 2018. High-Throughput Infrastructure for Advanced ITS Services: A Case Study on Air Pollution Monitoring. *IEEE Transactions on Intelligent Transportation Systems,* 19(7), pp.2246-2257.

[17] Yi, W., Lo, K., Mak, T., Leung, K., Leung, Y. and Meng, M. 2015. A survey of wireless sensor network based air pollution monitoring systems. *Sensors,* 15(12), pp.31392-31427.

[18] Jenab, K., Seyedhosseini, S.M., Khoury, S. and Sarfaraz, A. 2012. An intelligent air quality monitoring model in manufacturing. *Clean Technologies and Environmental Policy,* 14(5), pp.917-923.

[19] Guanochanga, B., Cachipuendo, R., Fuertes, W., Salvador, S., Benítez, D.S., Toulkeridis, T., Torres, J., Villacís, C., Tapia, F. and Meneses, F. 2018. November. Real-time air pollution monitoring systems using wireless sensor networks connected in a cloud-computing wrapped up web services. In Proceedings of the Future Technologies Conference (pp. 171-184). Springer, Cham.

[20] N Genikomsakis, Konstantinos, et al. "Development and On-Field testing of Low-Cost portable system for monitoring PM2. 5 concentrations." Sensors 18.4 (2018): 1056.

[21] Doni, A., Murthy, C. and Kurian, M.Z. 2018. Survey on multi sensor-based air and water quality monitoring using IoT. *Indian J Sci Res,* 17(2), pp.147-153.

[22] Kumar, S, and Ashish J. 2017. "Air quality monitoring system based on IoT using Raspberry Pi." International Conference on Computing, Communication, and Automation (ICCCA). IEEE, 2017.

[23] Parmar, G., Lakhani, S. and Chattopadhyay, M.K. 2017. October. An IoT based low-cost air pollution monitoring system. In 2017 International Conference on Recent Innovations in Signal Processing and Embedded Systems (RISE) (pp. 524-528). IEEE.

[24] Xiaojun, C., Xianpeng, L. and Peng, X. 2015. January. IOT-based air pollution monitoring and forecasting system. In 2015 International Conference on Computer and Computational Sciences (ICCCS) (pp. 257-260). IEEE.

[25] Souvik, M., Bhunia, S.S. and Mukherjee, N. 2014. "Vehicular pollution monitoring using IoT." International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2014). IEEE, 2014.

[26] Alvear, O., Calafate, C., Cano, J.C. and Manzoni, P. 2018. Crowdsensing in smart cities: overview, platforms, and environment sensing issues. *Sensors,* 18(2), p.460.

[27] Safia, A., Aghbari, Z. and Kamel, I. 2017. Efficient data collection by the mobile sink to detect phenomena in the internet of things. *Information*, 8(4), p.123.

[28] Miles, A., Zaslavsky, A., and Browne, C. 2018. IoT-based decision support system for monitoring and mitigating atmospheric pollution in smart cities. *Journal of Decision Systems,* 27(sup1), pp.56-67.

[29] Markus, K., Breitegger, P., and Bergmann, A. 2018. "Low-Power Wide-Area technologies as building block for smart sensors in air quality measurements." e & i Elektrotechnik und Informationstechnik, 135(6), pp.416-422.

[30] Liu, S., Xia, C., and Zhao, Z. 2016. October. A low-power real-time air quality monitoring system using lpwan based on Lora. In 2016 13th IEEE International Conference on Solid-State and Integrated Circuit Technology (ICSICT) (pp. 379-381). IEEE

[31] Pal, P., Gupta, R., Tiwari, S. and Sharma, A. 2017. IoT based air pollution monitoring system using Arduino. *International Research Journal of Engineering and Technology (IRJET)* (2017).

[32] Rushikesh, Ramagiri, and Chandra Mohan Reddy Sivappagari. "Development of IoT based vehicular pollution monitoring system." 2015 International Conference on Green Computing and Internet of Things (ICGCIoT). IEEE, 2015.

[33] Luo, L., Zhang, Y., Pearson, B., Ling, Z., Yu, H. and Fu, X. 2018. On the Security and Data Integrity of Low-Cost Sensor Networks for Air Quality Monitoring. *Sensors,* 18(12), p.4451.
[34] Balasubramaniyan, C. and Manivannan, D. 2016. Iot enabled air quality monitoring system (AQMS) using raspberry Pi. *Indian Journal of Science and Technology,* 9(39), pp.1-6.
[35] Jamil, M.S., Jamil, M.A., Mazhar, A., Ikram, A., Ahmed, A. and Munawar, U. 2015. Smart environment monitoring system by employing wireless sensor networks on vehicles for pollution free smart cities. *Procedia Engineering*, 107, pp.480-484.
[36] Pandikumar, S. and Vetrivel, R.S. 2014. Internet of things based architecture of web and smart home interface using GSM. *International Journal of Innovative Research in Science, Engineering and Technology*, 3(3), pp.1721-1727.
[37] Mahajan, S., Chen, L.J., and Tsai, T.C. 2018. Short-Term PM2. 5 Forecasting Using Exponential Smoothing Method: A Comparative Analysis. *Sensors,* 18(10), p.3223.
[38] Saha, H.N., Auddy, S., Chatterjee, A., Pal, S., Pandey, S., Singh, R., Singh, R., Sharan, P., Banerjee, S., Ghosh, D. and Maity, A. 2017. August. Pollution control using the Internet of Things (IoT). In 2017 8th Annual Industrial Automation and Electromechanical Engineering.
[39] Cheng, Y., Li, X., Li, Z., Jiang, S., Li, Y., Jia, J. and Jiang, X. 2014. November. AirCloud: a cloud-based air-quality monitoring system for everyone. In Proceedings of the 12th ACM Conference on Embedded Network Sensor Systems (pp. 251-265). ACM. Conference (IEMECON) (pp. 65-68). IEEE.
[40] Fadeyi, Johnson, Elisha Didam Markus, and Adnan M. Abu-Mahfouz. "Technology Coexistence in LPWANs-A Comparative Analysis for Spectrum Optimization." 2019 IEEE 28th International Symposium on Industrial Electronics (ISIE). IEEE, 2019.
[41] Molefi, M., Markus, E.D. and Abu-Mahfouz, A., 2019, January. Wireless Power Transfer for LoRa Low-Power wide-area Networks (LPWANs). *In 2019 Southern African Universities Power Engineering Conference/Robotics and Mechatronics/Pattern Recognition Association of South Africa (SAUPEC/RobMech/PRASA)* (pp. 105-110). IEEE.
[42] Liu, Jen-Hao, et al. "AN AIR QUALITY MONITORING SYSTEM FOR URBAN AREAS BASED ON THE TECHNOLOGY OF WIRELESS SENSOR NETWORKS." International Journal on Smart Sensing & Intelligent Systems 5.1 (2012).
[43] Lee, H.C. and Ke, K.H. 2018. Monitoring of large-area IoT sensors using a LoRa wireless mesh network system: Design and evaluation. *IEEE Transactions on Instrumentation and Measurement,* 67(9), pp.2177-2187.
[44] Dhingra, S., Madda, R.B., Gandomi, A.H., Patan, R. and Daneshmand, M., 2019. Internet of Things Mobile-Air Pollution Monitoring System (IoT-Mobair). IEEE Internet of Things Journal.
[45] Ma, Y., Yang, S., Huang, Z., Hou, Y., Cui, L. and Yang, D., 2014, c December. Hierarchical air quality monitoring system design. In 2014 International Symposium on Integrated Circuits (ISIC) (pp. 284-287). IEEE.
[46] Rosmiati, M., Rizal, M.F., Susanti, F. and Alfisyahrin, G.F., 2019. Air pollution monitoring system using LoRa modul as transceiver system. Telkomnika, 17(2), pp.586-592.
[47] Siregar, B., Nasution, A.B.A. and Fahmi, F., 2016, July. Integrated pollution monitoring system for smart city. In 2016 International Conference on ICT For Smart Society (ICISS)(pp. 49-52). IEEE.
[48] Mihăiţă, A.S., Dupont, L., Chery, O., Camargo, M. and Cai, C., 2019. Evaluating air quality by combining stationary, smart mobile pollution monitoring and data-driven modelling. Journal of Cleaner Production, 221, pp.398-418.
[49] Osunmakinde, Isaac O. "Towards safety from toxic gases in underground mines using wireless sensor networks and ambient intelligence." International Journal of Distributed Sensor Networks 9.2 (2013): 159273.
[50] Taylan, Osman. "Modelling and analysis of ozone concentration by artificial intelligent techniques for estimating air quality." Atmospheric environment 150 (2017): 356-365.
[51] Martínez-España, Raquel, et al. "Air-Pollution Prediction in Smart Cities through Machine Learning Methods: A Case of Study in Murcia, Spain." J. UCS 24.3 (2018): 261-276.
[52] Cecilia, José M., et al. "High-Throughput Infrastructure for Advanced ITS Services: A Case Study on Air Pollution Monitoring." IEEE Transactions on Intelligent Transportation Systems 19.7 (2018): 2246-2257
[53] Pandikumar, S. and Vetrivel, R.S., 2014. Internet of things based architecture of web and smart home interface using GSM. International Journal of Innovative Research in Science, Engineering and Technology, 3(3), pp.1721-1727.