Leveraging Machine Learning for Ambient Air Pollutant Prediction: The Zambian Mining Environment Context

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Abstract

Air quality monitoring in Zambian mining towns is an important issue due to the high levels of pollution caused by mining activities. Zambia is a country rich in minerals and mining is a significant contributor to its economy. However, mining activities have also led to increased levels of air pollution in mining towns, affecting the health of local communities. According to the Ministry of Mines, the major sources of air pollution in the Copperbelt are smelters, mining, and quarrying among others. Additionally, the Ministry of Mines reports that major pollutants include sulfur dioxide (SO_2), oxides of nitrogen (NOx), particulate matter, carbon monoxide (CO), dust, Carbon dioxide, etc. There are several government agencies engaged in management that can help with these environmental issues, including the Zambia Environmental Management Agency (ZEMA). The research was investigated by using a thorough review of the literature, furthermore, a qualitative study was conducted at ZEMA the primary institution for environmental monitoring, and specifically, interviews were conducted. This was done in order to gain an in-depth overview of the current state of the art for environmental pollutant monitoring in affected mining towns. According to the findings presented here, the country has not made enough investments in environmental monitoring technologies and instead relies on funded projects that render the agency responsible for preventing and controlling ambient pollution inoperable after the projects are completed, despite the fact that there are plenty of mineral resources available and more are still to be discovered. The research suggested new techniques for comparing ambient air pollutant levels to national guideline limits based on the limitations of its results.

Keywords: Ambient Air, Pollution, Zambian Mining, Machine Learning

I. INTRODUCTION

Copper, cobalt, gold, nickel, lead, silver, uranium, zinc, and other precious and semi-precious stones are among the mineral riches found in Zambia [5]. Although these minerals are found throughout the country, mining activity is primarily concentrated in the Copperbelt and North-Western Provinces. Copper mining first began in Zambia in the early 1900s, and during this time there was a significant increase in support facilities, including the construction of new towns, highways, and other commercial infrastructure, as well as significant investment in mine expansion [5]. Due to its potential to promote economic development, job creation, and the eradication of poverty, the mining industry has attracted significant national interest. By their very nature, mining, and mineral processing do have an impact on the ecosystem, and those consequences can last for a very long time [5]. According to Joanna et al [6], the main environmental problems associated with mines in Zambia are air pollution, among others. The environment, which includes people, plants, living things, and animals, depends on the atmosphere to survive [1]. When there are enough contaminants in the air to endanger human health, and harm plants, animals, and materials, this is known as ambient air pollution [1].

According to the Ministry of mines [7] The major sources of air pollution in the Copperbelt are smelters, mining, and quarrying among others. Additionally, [7] reports that major pollutants include Sulfur dioxide (SO_2), oxides of nitrogen (NOx), particulate matter, carbon monoxide (CO), dust, Carbon dioxide, etc. Phenny et al. [5] pointed out that these pollutants' effects on local populations are not as severe as those of SO_2 and PM, whose destruction is quite noticeable in the Copperbelt Province. PTB and other respiratory problems linked to air pollution are among the illnesses that residents of mining communities, especially Mufulira, complain about, as reported by Burnett [8]. Burnett [8] further points out that while these concerns were probably reflective of the long-standing hardships individuals in these mining towns have faced, the lack of research-based data made it challenging for the government to take any corrective action.

A. Zambian Laws, Regulations, and Policies

There are numerous environmental laws, legislations, and regulations in place to address these environmental issues. The Zambia Environmental Management Agency (ZEMA) is created by the Environmental Management Act of 2011[9], which gives it the authority to carry out "all such activities as are required to ensure the sustainable management of natural resources and protection of the environment as well as pollution prevention and control," according to section 9(1). As seen from its mandate, the role of ZEMA is administrative, meaning theirs is to protect the environment, and to do so, ZEMA is further guided by the Environmental Protection and Pollution Control Act[10] to monitor ambient air quality per the guidelines set out in the

first schedule to protect the general health, safety, or welfare of people, animals, plants, or other property that may be impacted by the operations, industrial processes, or commercial ventures performed by an operator. The following list of ambient air guideline limits is provided:

TABLE 1. AMBIENT AIR POLLUTANTS GUIDELINE LIMITS [10]

	parameter		*Reference time*	*Guideline limit*
1	Sulfur dioxide (SO_2)		10 minutes	500 µg/m^3
			1 hour	350 µg/m^3
2	Sulfur dioxide (SO_2) in combination with total suspended particles (TSP)[1] and (PM_{10})	SO_2	24 hours	125 µg/m^3
			6 months	50 µg/m^3
		TPS	24 hours	120 µg/m^3
			6 months	50 µg/m^3
		PM_{10}	24 hours	70 µg/m^3
3	Respirable particulate matter (PM_{10})[2]	PM_{10}	24 hours	70 µg/m^3
4	Oxides of nitrogen (NOx)		1 hour	400 µg/m^3
			24 hours	150 µg/m^3
5	Carbon monoxide (CO)		15 minutes	100 µg/m^3
			30 minutes	60 µg/m^3
			1 hour	30 µg/m^3
			8 hours	10 µg/m^3
6	Ambient Lead (Pb)		3 months	1.5 µg/m^3
			12 months	1.0 µg/m^3
7	Dustfall		30 days	7.5 tonnes/km^2

[1] Total suspended particles (TSP) are particles with a diameter of fewer than 45 micrometers (mm).
[2] Respirable particles (PM10) are particles with a diameter of fewer than 10 micrometers (mm). These can penetrate the ancilliated regions of the deep lung

B. *Challenges and open issues*

Despite ZEMA's existence, [6] observes that the agency lacks the staffing necessary to fully pursue compliance monitoring and auditing as well as limited resources to carry out its duty. [6] adds that the current legal framework is largely not being put into practice due to the lack of effective supervision over the environmental performance of the mines and suggests that more industry surveillance is urgently needed to improve the legislation's implementation. According to [6], inadequate controls are the reason mining companies continue to produce SO_2 above local, state, and federal restrictions. [11] noted as well that ZEMA and the local authorities lack the resources necessary to inform the many stakeholders on the state of the environment and the different types of pollution that the communities may be facing. Based on the preliminary findings that were insufficient, this study, therefore, sought to further investigate by asking the following research question:

- What techniques are currently being used to monitor ambient air pollutants in Zambian mining environments?

To find answers to the research question above, the study employed a substantive literature review as well as a qualitative method with the target institution being ZEMA as the main institution for environmental monitoring specifically interviews were conducted to understand the situation in depth, and the results of these findings are discussed under the literature review section.

C. *Significance of this study*

The foundation of human existence is the quality of the air. All governmental initiatives, both at the national and international levels, prioritize the need for clean air. A study of this kind is essential because it gives us the chance to understand the current state of mining environmental monitoring better. Consequently, as researchers we will have the chance to identify any gaps that need to be filled in order to offer research-based solutions that relevant stakeholders can use, which will ultimately improve the protection of human health and the environment.

II. LITERATURE REVIEW

Air pollution poses a serious threat to health and has a variety of negative effects on mining-related environments. Elisha et al. [12] points out that keeping track of air pollution levels enables environmental managers and other relevant stakeholders to develop suitable corrective actions as well as analyze and monitor compliance with rules. As a result, this area of the literature examines other similar publications as well as the current techniques used to monitor the environment.

A. *Monitoring methods by ZEMA*

A qualitative analysis was done, and specifically, interviews were conducted at the ZEMA offices in Ndola Copperbelt, in order to acquire a deeper knowledge of the processes and procedures being used by ZEMA to carry out its mandate as mandated by the Environmental Management Act of 2011[9]. The findings showed that ZEMA used the following methods for monitoring ambient air pollutants:

- To assess a mine's compliance with the emission limit value at the source, a portable stack emission monitoring device is employed.
- Ambient air Mobile equipment also called a caravan procured under the support of ZMERIP (Zambia Mining and Environmental Remediation and Improvement Project) whose obligation as part of its objectives is to support regulatory agencies with the enhancement of institutional capacity for environmental governance and compliance through policy support and capacity building. The mobile equipment is stationed in Lusaka and the Northern region. Sulfur dioxide, carbon monoxide, nitrogen dioxide, ozone, and total suspended particles are among the air pollutants that the caravan keeps an eye on. It also records climatic information like humidity, wind speed, and other variables. The caravan is equipped with solar panels to provide electricity for the system, a computer to track pollutants, gas sensor units to collect gases, and particulate refraction units to distinguish between particle sizes. A modem that connects the system to the main server in Lusaka and transmits data that is recorded in real-time after it is stationed to monitor is also installed in the caravan. Further information revealed that the caravan stays stationary at the office for storage when not in use and only moves when it's necessary to monitor a specific industry. A

simplified representation of the business procedure is shown in Fig. 1.

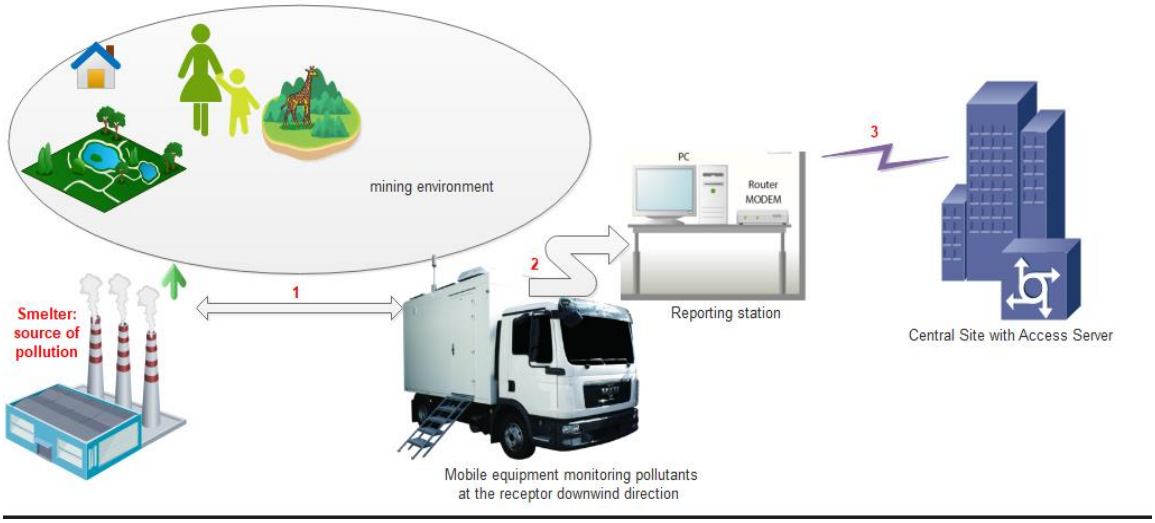

Fig. 1. Ambient air monitoring using the mobile equipment

a) Limitations of ZEMA monitoring methods

The study found various shortcomings with the existing approaches, including the portable stack emission equipment, which makes it hard to continuously monitor pollutants at the source because it necessitates the physical presence of an inspector and is not a real-time procedure. The transportable equipment's future, however, is uncertain because it is now being used as part of a project that will soon come to an end. The high expense of maintenance is one of the mobile equipment's significant drawbacks. If the mobile equipment is still in use after the project is complete, the government must equip the facility in addition to relying on projects to ensure that the caravans run because ZEMA may not have the resources to maintain the equipment. It was highlighted that the CEP (Copperbelt Environmental Project), which enabled the first transportable equipment in 2008, experienced a comparable situation. Due to their high cost, the institution neglected to maintain them after the project was completed, therefore they are now non-functional and have been packed. Due to this issue, the institution didn't have any operating mobile equipment until around 2020, when they acquired one that is currently functional. Since the technology is portable, nobody could undertake monitoring duties because of the rigorous Covid-19 requirements when it was first received in 2020, when the world was struck by the epidemic. It was also observed that the system lacks modeling functionality because it was just intended to be a reporting system, despite having a dataset of contaminants that have been captured. Finally, the fact that there is only one caravan in the northern region, which is now restricted to just three towns Kitwe, Chingola, and Mufulira which are all known for having a lot of mining activities translates to insufficient surveillance.

B. Related works

Muma et al.'s [11] investigation looked into the impact of mining effluent discharge and sulfur dioxide emissions on the quality of the air and water in the Kankoyo township of the Mufulira area. The S5001 SO2 analyzer series was used in the investigation, and air samples from the ambient air in Kankoyo Township of the Mufulira district were used to acquire monthly average results. Their study reported that some months during their sampling period did not report average readings due to equipment breakdown. This study is not however clear on how the captured pollutants were stored to help in quick decision-making.

In a separate study, Elisha et al. [12] examined the impacts of sulfur dioxide on plants and people in the Kitwe district. The SO_2 gas samples were taken once a week using a flue gas analyzer probe that was installed on a sampling point on a stack. Because the process is done sporadically and lacks real-time capability, it is not very effective for pollutant monitoring and enforcing compliance.

The study by Stephen and Moono [13] examined how mining has a harmful impact on the ecosystem, especially Sulfur Dioxide (SO_2). The study was a case study of the Copperbelt Province's Kankoyo Township in the Mufulira district. The researchers used ZEMA historical data based on four years as an indirect means of obtaining the smelter's air pollution statistics (2011-2014). According to reports, the mining company's prohibitions on conducting direct trapped emissions from the smelter were to blame.

According to the studied literature, Zambian mining environments are under-monitored and do not make use of technology as it develops. In this digital age, technology is radically altering how organizations operate. To run their processes more effectively and sustainably, utilities, oil, gas, energy, manufacturing, and construction industries are all integrating IoT, machine learning, and other AI solutions.

III. PROPOSED FUTURE WORKS

According to Chetan et al. [2], the development of machine learning has made it possible to create prediction models for monitoring and managing pollution using real-time data.

Khalid et al. [3] adds that numerous tactics have been developed to reduce air pollution. Among these, air quality prediction (expressed as air pollution warning systems) has emerged as a practical way to spot trends in local and worldwide air pollution levels. Predicting air quality is essential for enhancing both environmental sensing research and human well-being [4].

Based on the limitations in the findings, to support ZEMA's monitoring work without directly contributing to its staff body, this study proposes to:

- Develop a machine learning model for ambient air pollutant level analysis and prediction to help regulators make informed decisions about the management of air quality in the mine environments.
- To address the challenge of intermittent monitoring the study proposes to develop a cost-effective real-time IoT-based tool for ambient air pollutant concentration level monitoring and reporting.
- A smart emission surveillance system that integrates (1) and (2) to provide the various stakeholders with prediction results on the state of the environment and alert when pollutant concentration levels exceed guideline limits to allow users to take immediate action of reducing exposure to pollutants.
- And lastly, Choropleth risk visualization map incorporation to allow various stakeholders to view air pollutant distribution to help identify mining environments that require mitigation efforts of reducing exposure to air pollutants and prevent health risks.
- . Fig 2 shows the workflow presentation of the proposed approach.

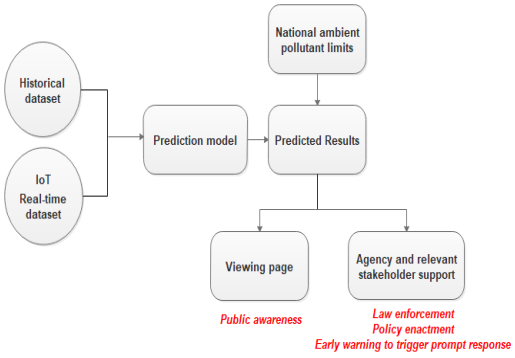

Fig.2. a proposed approach for environmental monitoring

IV. CONCLUSION

It is worth noting that air pollution in mining towns is a serious issue and has a significant negative impact on the health and well-being of local communities, therefore it's important to have accurate air quality monitoring programs in place to help mitigate the problem. The study has established however that despite the given abundance of mineral resources and more yet to be explored, the country has not adequately invested in environmental monitoring technologies besides relying on funded projects that leave the agency mandated to prevent and control ambient pollution incapacitated after the projects are long gone failing to maintain the highly expensive donated systems. Given these difficulties, [14] suggests that local strategies for preventing hazardous contamination should be promoted. In order to improve the quality of life for those who are particularly impacted by mining environments, the study is proposing cost-effective methods of environmental monitoring leveraging machine learning and IoT capabilities for air quality prediction. By alerting on potential health risks, which will trigger response measures to mitigate the impact of high pollutant levels as well as contribute to policy enactment, among other things,

ACKNOWLEDGMENTS

The study's sponsors, Copperbelt University Africa Centre of Excellence for Sustainable Mining (CBU-ACESM) are much appreciated and acknowledged.

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