Mitigating the Impacts of Environmental Pollution in Lejweleputswa District Through Integration of Local and Scientific Knowledge

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Abstract. South Africa is home to extensive mining activities, although it is good for the economy it is also one of the more serious environmental problems such as air pollution, which is a major contributor to health issues and inability to grow crops within mining communities. Though the concerned industries (such as mining) and governments have developed environmental management systems/plans to identify, prevent/mitigate the impacts the mining activities have on the society, the effects of these plans have done little to redress the threats facing the community. The main reason for this is the lack of appropriate and comprehensible air pollution monitoring systems that are specifically targeted to the at-risk local communities. Sustainable, timely, and relevant air pollution monitoring systems enables communities to mitigate the negative impacts easily. Current pollution systems are fraught with challenges of not having adequate coverage by air quality monitoring stations, hence leaving small-rural communities unattended. These communities are left with only one option; consulting their own local knowledge to observe and mitigate air pollution. In this paper, we demonstrate the integration of scientific and local knowledge in monitoring air pollution for the district of Lejweleputswa, Free State, South Africa. Fuzzy Cognitive Maps was utilized as a tool to analyze, verify or validating local knowledge whereas Wireless Sensor Network (WSN) was used as a scientific approach to collect pollutants.

Keywords: Fuzzy Cognitive Maps (FCMs) · Local knowledge · Pollution monitoring system · Wireless Sensor Networks (WSN) · Lejweleputswa

1 Introduction

Mining contributes to the economy of South Africa, resulting in positive impacts such as employment and enrichment of community members' lives. Though there are positive impacts, negative impacts still exist, as their operations are unsettling to the environment; they often pollute our natural resources, and thus have led to adverse impacts on surrounding communities as well as wildlife [1]. For the purposes of this paper, pollution can be defined as "addition of undesirable material into the environment because of

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human activities". Throughout the years, substantial metals have been discharged from mines into the earth leaving enormous measures of mine dumps and corrosive mine waste [2]. This has left mining networks in the locale of Lejweleputswa helpless against tuberculosis (TB) [3]. The greatest test confronting the mining business is to demonstrate that it adds to the government assistance and prosperity of the present age without trading off the personal satisfaction of people in the future [4]. Regions, for example, Mangaung Metropolitan and Vaal Triangle, have conventional contamination checking stations that report to contamination observing frameworks, for example, South African Air Quality Information System (SAAQIS). Notwithstanding, the quantity of these stations is generally extremely little and there is no satisfactory information assembled for assessment in little networks, for example, Lejweleputswa. Besides, the utilization and importance of SAAQIS, is new to the semi-unskilled and ignorant mining networks in Lejweleputswa. Their strategies for getting to and spreading results make it increasingly hard for the networks to comprehend. In this manner, these networks keep on relying more upon their neighborhood information for watching and checking air contamination; they have watched and encountered the progressions throughout the years. Neighborhood information is depicted as "information that individuals in a given network have created after some time, and keep on creating; it depends on understanding, regularly tried over hundreds of years of utilization, adjusted to the local human progress and condition, implanted in network rehearses, organizations, connections and customs, held by people or networks and it is dynamic and ever evolving" [5].

Local information is indispensable with regards to having a reasonable human race, everybody's information and association is required for dynamic in regards to the earth. Individuals' view of and disposition towards environmental change, dry season or natural contamination is basic in diminishing introduction among individuals and can likewise impact the reaction to mediation that are planned for empowering deportment change [6]. This information helps to guarantee that strategy and correspondence systems accomplish change in open mentalities, subsequently recognizing the significance of the mind that individuals have about the earth. Right now, examine approach was received because of the idea of the investigation. This methodology was regarded appropriate on the grounds that it investigates the exploration question and it is applied to get a firm comprehension of the objective respondent(s) information, conclusions and conduct related with the examination.

Local people accept that present logical arrangements like those that are referenced here don't generally address their issues, reason being that these arrangements are simply "transfer of innovation" from logical specialists to them. Concerned local people enduring the most extreme dangers and wellbeing impacts by mining exercises are requesting a more prominent job in examining, portraying, and upholding answers for alleviate the nearby risk's they face. One of the exploration question was, "To what expand can an air pollution monitoring framework that coordinates local information alleviate impacts related with pollution and be satisfactory by mining areas of Lejweleputswa District?" The central objective of this examination was to build up a versatile air pollution observing model that incorporates local with scientific information to report about pollution to the mining areas of Lejweleputswa District.

2 Related Literature

2.1 An Overview of Air Pollution by Mines

There are different forms of environmental pollution; air, soil, water, light, noise, thermal and visual; this study focuses on air pollution. Air pollution occurs when gaseous substances, dust, fumes, or odor in high volumes, which could be harmful to the health or comfort of humans, cause damage to fauna and flora, affects air. Air pollution in Africa is estimated to exceed the limits set by of World Health Organization by 10 to 30 times [7]. Since the discovery of gold in the Witwatersrand Goldfields in 1886 (the Goldfields consists of 7 basins including Lejweleputswa), gold mining resulted in the establishment of more than 270 mine dumps, containing more than 6 billion tons of tailings(waste) and some 600 000 tons of uranium, and covering 400 km^2 [8].

Dust from mine dumps is known to be an irritant especially during windy seasons, and it is a health risk to communities living near them; this has necessitated the need to find appropriate coping mechanisms to protect themselves [9]. Trying to eliminate the impact that mine dumps have on the communities, Harmony Gold (one of the mining companies) started rehabilitating the dumps to reduce the level of pollution and also try and reclaim the land that the dumps are sitting on to economic account rather than just restores it to open field as the mine laws dictates [3]. This has decreased the number of dumps around Matjhabeng, but there are many more still remaining.

2.2 Local Knowledge and ICTs

To manage the scope, density and ambiguity of global environmental problems, it is important to take into account different types and sources of knowledge to form an adaptive co-management approach [9]. Researchers today agree that local knowledge and modern science complement each other for example, ITIKI a drought prediction tool that bridges a gap between indigenous and modern science [10]. Integrating local and indigenous knowledge with science for hydro-meteorological disaster risk reduction and climate change adaptation in coastal and small island communities [11].

Local knowledge has been a useful tool for the community in terms of mitigating the impacts of pollution and coming up with coping mechanisms. The issue has always been the level of effectives and usability but careful integration of local knowledge present opportunities especially in the dissemination process of monitored pollution to mining communities in Lejweleputswa because this supports ways that are appropriate and locally relevant to the people. The cost of installing a single pollution monitoring station is around thousands of rands. In contrast, local knowledge is cheap and time-saving. However, with ICT revolution and climate change it is impossible to talk about local knowledge in isolation. The ICT component with highest potential as compared to monitoring station is wireless sensor network. WSNs are fully scalable, cost effective and they do not depend on any preexisting infrastructure and can be redeployed or expanded easily [12]. Once deployed, the nodes are able to detect pollutants and monitor parameters that contribute to environmental pollution with better accuracy as compared to distant monitoring stations. WSNs can be deployed in large numbers in order to accurately measure parameters such as temperature, methane (CH_4), ethylene (C_2H_4), ammonia

(NH_3), benzene (C_7H_8), LPG (C_4H_{10}), CO_2, CO and nitrogen oxides (NO_x). These readings can then be used, together with other less obvious aspects of local knowledge (such as observed Particles from mine dumps/Closed mine shafts/Acid mine drainage) to improve monitoring.

2.3 Fuzzy Cognitive Maps (FCMs)

Originally developed by Kosko (1986) as a semi quantitative and dynamic method to structure expert knowledge, FCM has historical roots in cognitive mapping (Axelrod 1976). Similar to other cognitive maps, FCMs are graphical representations of a system that visually illustrate the relationships or edges between key concepts, or nodes, of the system, including feedback relationships [13]. FCMs enables creation of concepts out of people's perceptions and integrating them into the system; this is a better way of getting a broader view of how the community understands their environment.

FCM Model for Air Pollution Monitoring System. Local communities depend or trust information they learned for themselves, information that is based on what they have seen or experienced over time. For the monitoring system to be acceptable and understood by locals, it must be adaptive. The system should be able to cater for the already available knowledge from the locals, knowledge on how to observe, monitor and cope with air pollution around them. FCMs were used as a tool to collect, verify and validate this local knowledge in order for it to be integrated within the system. The concepts identified during local knowledge understanding and analysis (white dust, orange water, black soil, white soil, gaseous smell, air moisture, foul smell, particles from mine dumps, rain, wind and acid mine drainage) were uniquely structured by their respective positions. Each indicator represents a concept in an FCM model (C1…Cn); these concepts are linked by weights to determine the causality of one concept to the other. The causal effects between the concepts (local knowledge indicators) were declared using values, in a closed set of range [−1, 1]. These values are represented in linguistic values: {strong positive (1), medium positive (0.5), low positive (0.25), none (0), low negative (−0.25), medium negative (−0.5) and strong negative (−1)} from the mental modeler tool being used. This section provides more clarity about the concepts and their dependencies. In this portion, a matrix is designed as show in Table 1. This matrix is called as weight matrix. The names of all the concepts are written as row heading and concepts symbol like C1, C2, etc., are written as column headings were each cell contains a value.

During a scenario simulation, changes are made to the matrix to see how the system might react to plausible changes of health or environmental components within the system. From the 18 concepts represented in Table 1, the matching relationships were graphically represented as shown in Fig. 1. These relationships describe the impact of one concept on the other concept. If the relationship is directly proportional, then a positive value on the arc is written. Directly proportional means that a concept is directly affecting on the other. This effect may be either increasing or decreasing order. For example, wind has direct relation with particles from mine dumps, meaning that when it is windy the particles form of dust make way into the environment resulting in air pollution. If the relationship is inversely proportional, then negative value on the arc is written. Inversely proportional means that concept is inversely effecting the other. For example, if it is

Table 1. Causal effects representation

Concepts	Symbol	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}
Rain	C_1	0	−1	1	0	0	0.25	0	0	0	0	0	0	0	0	0	0	0	0
White dust	C_2	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0.5	0.5	0.5	1
Acid mine drainage	C_3	0	0	0	0	0	0.5	1	0	0	0	0	0	0	0	0	0	0	0
Wind	C_4	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Particles from mine dumps	C_5	0	1	0	0	0	0	0	0	0.25	0	0	0	0	0	0	0	0	0
Black soil	C_6	0	0	0	0	0	0	0	0	0	0	0	−1	0	0	0	0	0	0
Orange water	C_7	0	0	0	0	0	0	0.5	1	0	0	0	0	0	0	0	0.5	0	0
Foul smell	C_8	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.25	0	0	0	0
White soil	C_9	0	0	0	0	0	0	0	0	0	0	0	−1	0	0	0	0	0	0
Gaseous smell	C_{10}	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0
Atmospheric moist	C_{11}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Soil fertility	C_{12}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asthma	C_{13}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eczema	C_{14}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eyes irritation	C_{15}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Skin irritation	C_{16}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lung cancer	C_{17}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tuberculosis	C_{18}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

rainy, we have less particles from mine dumps resulting in less air pollution. No arc is drawn if there is no relation between two concepts. Even in weight matrix value, zero (0) is written. Zero represents no relation between concepts. For example, there is no relation between foul smell ad gaseous smell.

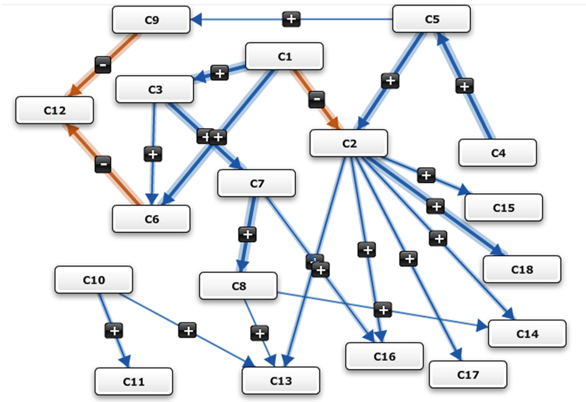

Fig. 1. Relationship between indicators

Scenarios were embraced to decide how the framework may respond to conceivable changes to wellbeing or environmental parts inside the framework. The Scenario interface of Mental Modeler permits the dynamic impacts of interchange the board intercession situations, given the present degree of gathering comprehension of the framework, to be assessed. For example, as a result of building a mutual network model of the air monitoring framework, focus groups in Lejweleputswa region built up a speculation that restoring mine dumps may ease air contamination. A few situations could be proposed and run progressively to perceive the adjustment of the air observing framework and what should be possible to diminish the degree of effect pollution has in the Nyakallong area.

3 Integration Framework

The framework comprises of three elements (data collection, monitoring, and visualization) that work together to produce an integrated system. It is designed around the generic early warning system framework developed by the United Nations Office for Disaster Risk Reduction (UNISDR) [14] (Fig. 2).

3.1 Architecture Design

Capturing Sensor Data. Remote sensors dependent on the Libelium gas sensor board introduced in chosen areas measure the accompanying natural parameters: temperature, carbon monoxide, carbon dioxide, and methane. At present, the sensors take readings each 30 min and the qualities put away in a removable memory card. In corresponding

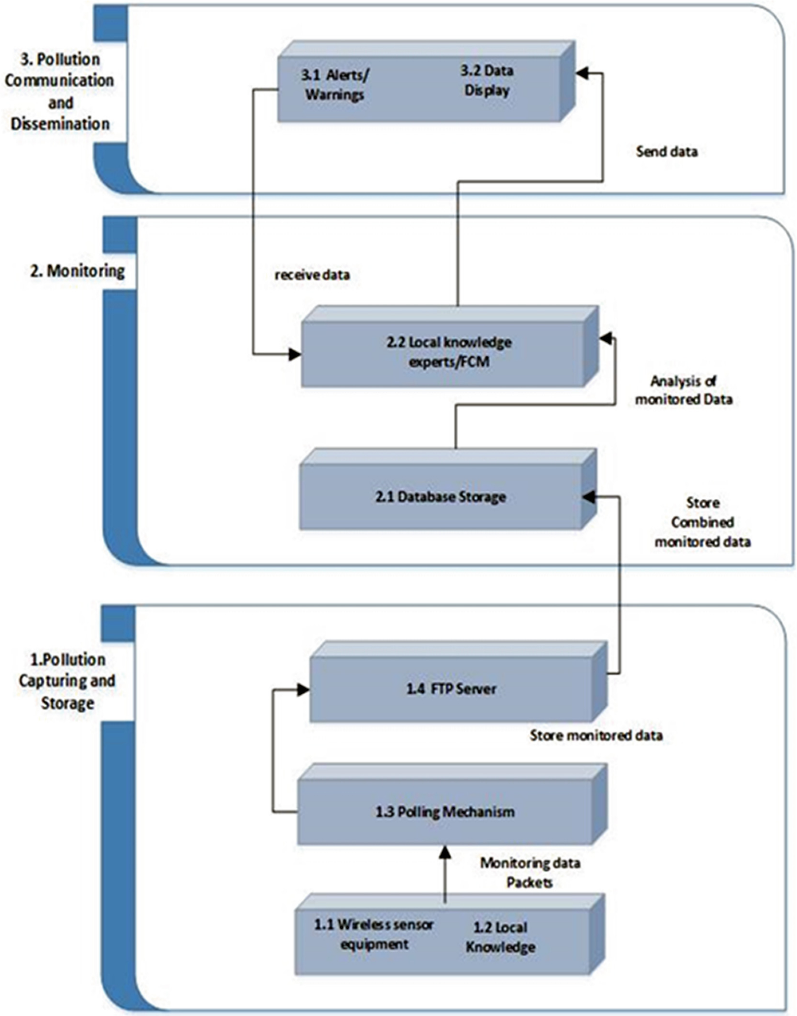

Fig. 2. Adaptive air monitoring system architecture

with this technique, the sensors send hourly normal readings (figured from the 30 min interim readings) to the server as instant messages (SMS). Information from the Secure Digital (SD) cards are physically transferred to the server after at regular intervals. The sensor readings are naturally transmitted as instant messages (GPRS/GSM) to the database at foreordained interims. The biggest bottleneck to the sensors 'operation is the GPRS module that frequently fails and cuts-off the communication between the sensors and the system, this is as a result of the antenna not functioning well as well as the depletion of airtime by the SIM card used by the module. For future deployments, this will be resolved by use of the XBee Radio and XBee Antennas in replacement of GPRS module.

Capturing Local Knowledge. The system was developed to work with local knowledge collected and processed by FCMs. LK was retrieved from FCMs and pre-stored in MySQL database as indicators to be observed. For the community targeted, an intermediary person (who understands both English, local language as well as ICT and LK) was identified and used as the interface to the community. Using a mobile smart phone application (Fig. 3), the intermediary keys in all the observations about the LK provided by the identified respondents as well as any extreme events taking place. Once the information is stored on the phone, it will be sent to MySQL database via the phone's internet facility. When internet is not available, the phone stores information on its internal storage and uploads it later when internet is available.

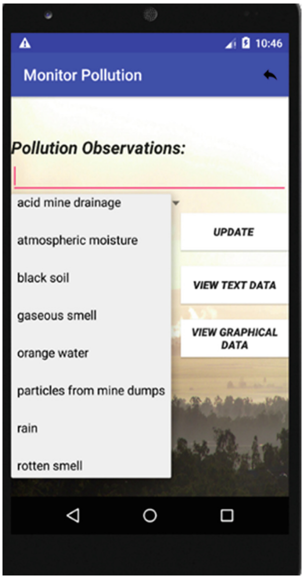

Fig. 3. Mobile phone application prototype

4 Implementation and Testing

4.1 Pollution Monitoring

The integration framework was implemented as a set of three components:

Sensor data that is received by the FTP server is sent to MySQL database after every 30 min for monitoring and then compared to the already provided quality standards. Local knowledge experts send in monitored observations into the system by using android mobile application (observations that relate to the already stored local knowledge indicators). For local knowledge, FCMs are used to bring together all the indicators from the focus group and produce a single FCM. Scenarios are created based on the changes being made to the indicators. The output of the scenarios is then formatted into readable form for storage in the database.

4.2 Pollution Knowledge Dissemination

Android Mobile Application and SMS Ability. The system provides three methods for dissemination based on user preference: The application takes in input from the end users such as any extreme event-taking place at that time, the event can then be disseminated to other registered users via SMS. The option of viewing graphical points of where pollution comes from is also available by Google Maps integration into the application (Fig. 4a). The system sends SMS alerts or warnings on current pollution status to registered users; this also caters for people with no smartphone. The users can also send in extreme events to the system using SMSs, the events are distributed to registered users of the system. The intermediary person is responsible for keying them in the android mobile application for storage on the database, then registered users are able to receive the extreme events by SMS receive the extreme events (Fig. 4b).

(a) (b)

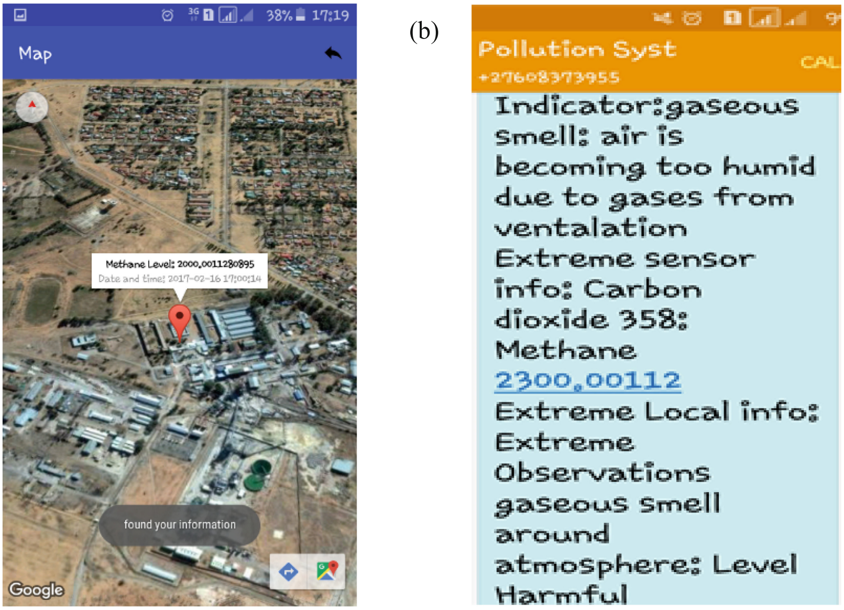

Fig. 4. a. Graphical view of monitored data. b. SMS alert

Web Portal. The web portal shows the status of pollution, the warnings, as well as extreme events. The option of viewing graphical points of where pollution comes from is also available by Google Maps integration (Fig. 5).

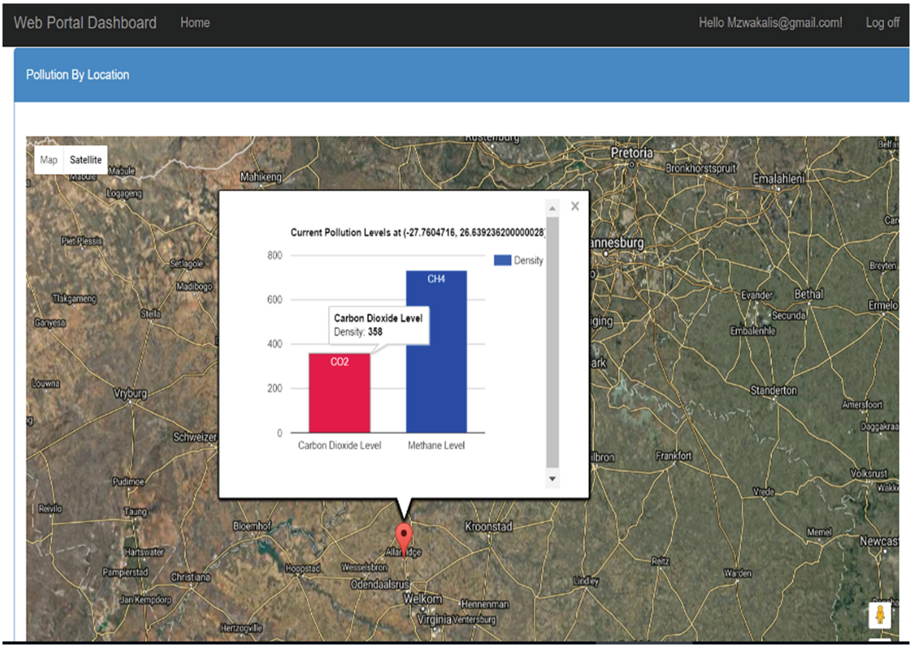

Fig. 5. Graphical view of monitored data on a web-portal

Table 2. Importance of System's Prototype Functionalities

	Not important	Fairly important	Neutral	Important	Very Important	No response
Monitoring with sensors	0%	0%	0%	20%	80%	0%
Monitoring with indicators	0%	0%	10%	20%	70%	0%
Google Map feature	0%	0%	20%	50%	30%	0%
Discussion board feature	0%	10%	30%	60%	0%	0%
SMS notification	0%	0%	0%	30%	70%	0%

4.3 Feedback on the System's Prototype Functionalities

Table 2 above summarizes the respondent(s) views regarding the functionalities provided by the prototype. Based on the results it is evident that the group found the use of monitoring pollution with sensors and indicators very important and the option of them receiving SMS notifications. The researcher demonstrated the system to the group and allowed them to interact with the prototype. Moreover, majority of the group (60%) rated the system as very important while 30% deemed the system as important and 10% were neutral to their response.

5 Conclusion and Further Work

In this paper, we have portrayed continuous research work that involves a system for coordinating from one perspective local knowledge and on the other scientific knowledge on air contamination utilizing cell phones, FCMs and WSNs. We have likewise depicted a framework model that actualizes this structure. So as to test the framework model in a genuine domain, it was conveyed in Nyakallong Allanridge in the Lejweleputswa locale.

Our pollution monitoring framework offers a special and promising arrangement that is versatile and reasonable. The utilization of local information contamination pointers, which are incorporated with pollution information read from remote sensors is a novel commitment. Further, through the spread segment, our answer gives significant pollution cautions to partners, particularly unskilled and semi-ignorant ranchers in the provincial regions of Africa. In addition, the utilization of less expensive cell phones (than proficient pollution stations) for pollution information assortment and for contamination dispersal makes the arrangement increasingly maintainable and moderate for mining networks. However, during meetings with the focus group members, the researcher learned of the most critical factors affecting the community, the air around the community is mostly affected by heavy metals and dust, their water, and soil are affected by heavy metals and acid. Our system did not provide all the necessary solutions for these problems. For that to happen, more sensor boards are being acquired and will be placed in mining communities. The required boards have to cater for the above-mentioned pollutants. In particular, Smart Water sensor board as well as agriculture sensor board will be acquired, this would aid the communities not just Nyakallong but across the district.

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