Development of an Adaptive Environmental Management System for Lejweleputswa District: A Participatory Approach through Fuzzy Cognitive Maps

Masters Dissertation

by

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DECLARATION

I, Mpho Josephine Mbele student number , declare that the work in this dissertation is a presentation of my original research work and has been submitted for the award of Masters in: Information Technology at the Central University of Technology, Free State. Wherever contributions of other people are involved, every effort has been made to indicate this clearly, with due reference to the literature and acknowledgement. Further, this work was done under the guidance of Muthoni Masinde and Itumeleng Kgololo-Ngowi, at the Central University of Technology, Free State.

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In our capacity as supervisors of this dissertation, we certify that the above statements are true to the best of our knowledge.

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ABSTRACT

Environmental pollution caused by mines within the district of Lejweleputswa in Free State is a major contributor to health issues and the inability to grow crops within the mining communities. Mining industries continue to develop environmental management systems/plans to mitigate the impact their operations has on the society. Even with these plans, there are still issues of environmental pollution affecting the society. Though there are Information Communication and Technology (ICT) based pollution monitoring solutions, their use is dismal due to lack of appreciation or understanding of how they disseminate information. Furthermore, non-adopting community members are being regarded as inherently conservative or irrational, but these community members argue that the recommendations and technologies brought to them are not always appropriate to their circumstances. There was concern that local people's knowledge of their environment, farming systems, and their social as well as economic situation had been ignored and underestimated when ICTs solutions are being implemented (Warburton & Martin, 1999). Another challenge is that there is no station to monitor pollution for small communities such as Nyakallong in the district. This result in mining communities depending on their own local knowledge to observe and monitor mining related environmental pollution. However, this local knowledge has never been tested scientifically or analysed to recognize its usability or effectiveness. Mining companies tend to ignore this knowledge from the communities as it is treated like common information with no much scientific value. As a step towards verifying or validating this local knowledge, fuzzy cognitive maps were used to model, analyse and represent this linguistic local knowledge.

Although this local knowledge assists in mitigating environmental pollution, incorporating it with scientific knowledge will improve its relevance, trustworthiness and acceptability by majority of community members and policy-makers. Information and Communication Technologies (ICTs) can accelerate this integration; this is the focus of this research.

The increased usages of Information Technology being witnessed today makes it the most important factor for the world to depend on for solutions to many of today's and tomorrow's problems. These solutions make use of various forms for dissemination purposes, one of the most versatile dissemination device is a mobile phone since majority of the world’s population do own a mobile phone. In this way information is easily accessible by almost everyone that needs it.

A novel environmental management solution was designed to work within the mining communities of Lejweleputswa. The research started off by designing a unique integration framework that creates the much-needed link between local knowledge and scientific knowledge. The framework was then converted into an adaptable environmental pollution management system prototype made up of three components; (1) gathering environmental pollution knowledge; (2) environmental monitoring and; (3) environmental dissemination and communication. To achieve sustainability, relevance and acceptability, local knowledge was integrated in each of the three components while mobile phones were used as both input and output devices for the system. In order to facilitate collection and conservation of local knowledge on environmental monitoring, an elaborate android-based mobile application was developed. Wireless sensor-based gas sensor boards were acquired, and deployed as a compliment to conventional monitoring stations, they were used to gather scientific knowledge. To allow for public access to the system’s data, a web portal and an SMS-based component were also implemented. In order to collect local knowledge from community, a case study of Nyakallong community in Lejweleputswa was carried out. On completion of the system prototype, it was evaluated by participants from the community; 90% of respondents gave a score of ‘*excellent* ‘.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AMD	Acid Mine Drainage
APK	Android Application Package
ATM	Automatic Teller Machine
BDS	Blue Drop System
CH_4	Methane
CO	Carbon Monoxide
$C0_2$	Carbon Dioxide
CM	Cognitive Maps
DAQ	Data-Acquisition Unit
DEA	Department of Environmental Affairs
FCM	Fuzzy Cognitive Maps
FTP	File Transfer Protocol
GPRS	General Packet Radio Service
GPS	Global Positioning System
HCN	Hydrogen Cyanide
H2S	Hydrogen Sulphide
ICT	Information Communication Technology
IDE	Integrated Development Environment
ITA	Integrated Toposequence Analysis
LK	Local Knowledge
MEB	Multiple Evidence Base
mm	millimetre
NH3	Ammonia
NO	Nitric Oxide
NO_2	Nitric Dioxide
O_2	Molecular Oxygen
O_3	Ozone
pH	potential of Hydrogen
PH_3	Phosphine
PM_{10}	Particulate Matter

ppm parts per million

SAAQIS South African Air Quality and Information Systems

SAWS South African Weather Service

SD Card Secure Digital Memory Card

SI System of Units

SIM Subscriber Identity Module

SMS Short Message Service

SO_2 Sulphur Dioxide

TB Tuberculosis

TOT Transfer of Technology

um Units of Measure

USB Universal Serial Bus

WaGoSy Water Resource Governance System

Wi-Fi Wireless Fidelity

WHO World Health Organization

WSN Wireless Sensor Networks

XP Extreme Programming

PUBLICATIONS

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1. INTRODUCTION AND BACKGROUND

1.1 BACKGROUND

South Africa is home to some of the deepest mines in the world and accounts for almost 50% of the world’s found gold reserves (Chamber of mines South Africa, 2014). Though mining is a major economic activity and often provides employment, mining operations are disruptive to the environment because they often pollute our natural resources, and thus have proven adverse impacts on surrounding communities as well as wildlife (Mabiletsa & Du Plessis, 2001).Waste from these gold mines constitutes the largest single source of waste and pollution in South Africa (Oelofse, et al., 2007). Pollution is an undesired change in the physical, chemical or biological characteristics of air, soil and water that may harmfully affect the life or create a potential health hazard of any living organisms (Pathak & Mandalia, 2011).

The mining industry is responsible for some of the largest releases of heavy metals into the environment, leaving a lot of mine dumps and acid mine drainage (Singh & Li, 2014). It has been found that mining communities and prisoners are susceptible to tuberculosis (TB); this is mostly due to mining operations in South Africa, communities living in Lejweleputswa in the Free State province, are part of these mining communities (Motsoaledi, 2014). The main challenge for the mining industry is to demonstrate that it contributes to the welfare and wellbeing of the current generation without compromising the quality of life of future generations (Azapagic, 2004).

Although South Africa has made significant progress in ensuring implementation of policy frameworks that address mine closures, air, soil, and water management, (including appropriate changes in practices by the mining industry), vulnerabilities in the current system still remain (Oelofse, et al., 2007).

South Africa’s more resource-endowed municipalities such as Mangaung Metropolitan and Vaal Triangle, use conventional pollution monitoring stations to continuously measure the most important pollutants and report to pollution monitoring systems such as South African Air Quality Information System (SAAQIS). However, the number of these stations is usually very small and in small communities, such as Lejweleputswa, not enough data is gathered for evaluation as tested by the researcher. Further, the use and relevance of the current monitoring systems such as SAAQIS and Blue Drop

System (BDS), are still alien to the rural (mostly semi-illiterate and illiterate) communities in Lejweleputswa. Their methods of accessing and distributing information make it more difficult for them to be used by the communities. Consequently, these communities continue to depend more on their local knowledge for observing and monitoring pollution because they have observed and experienced the changes over the years. Local knowledge is described as knowledge that people in a given community have developed over time, and continue to develop (Singh & Devine, 2013). It is based on experience, often tested over centuries of use, adapted to the local culture and environment, embedded in community practices, institutions, relationships and rituals, held by individuals or communities and it is dynamic and ever changing (Singh & Devine, 2013).

Local knowledge is crucial when it comes to having a sustainable world, everyone's input and participation is required to come up with better decisions regarding their environment. People's perceptions of and attitudes towards climate change, drought or environmental pollution is critical in reducing exposure among people and can also influence the response to interventions that are aimed at encouraging behaviour change (Muindi, et al., 2014).This knowledge helps to ensure that policy and communication frameworks achieve change in public attitudes, thereby acknowledging the importance of the understanding that people have about the environment.

1.2 PROBLEM STATEMENT

Communities in Lejweleputswa (Free State province, South Africa) are impacted by environmental pollution on their daily lives due to mining; this has become part of their existence. Locals believe that current scientific solutions like the ones mentioned in section 1.1 do not really address their problems, reason being that these solutions are just "transfer of technology" from scientific experts to them. Concerned locals suffering the utmost risks and health effects by mining activities are demanding a greater role in researching, describing, and advocating solutions to mitigate the local hazard's they face. The solutions are not adaptive to changes happening around the environment, they are not aware of when or how to look out for certain indicators. In most cases, scientific solutions are used to address issues associated with communities such as welfare, poverty and education.

The public still sees the relationship between science and their knowledge as a one-way flow of knowledge and information from scientifically trained researchers to communities, with little direct feedback or input from local people (Hulme, 2009). The Transfer of Technology (ToT) model was criticized because it only recognized scientists as the people capable of coming up with technologies and methods which address diverse conditions in poor Countries. This led to locals not adopting recommendations made to them (Amankwah, et al., 2015). Instead of the non-adopting community member being regarded as inherently conservative or irrational, Warburton and Martin argued that the recommendations and technologies were not always appropriate to the local member circumstances (Warburton & Martin, 1999). There was concern that rural people's knowledge of their environment and farming systems, and their social and economic situation had been ignored and underestimated (Warburton & Martin, 1999).

1.3 THE SOLUTION

The community members know more about the mining activities impacts they are faced with each day. The solution around the problem stated in section 1.2 was to ensure that the scientific solutions cater for knowledge from the affected communities through the integration of the two knowledge systems. An Adaptive Environmental Management System was developed to monitor environmental pollution and send out alerts that include local and scientific information whenever level of pollution is too high. This counterbalances the weaknesses, of the two approaches, resulting in some kind of hybrid knowledge that is critical for promoting sustainable environment, and also to create an adaptive system that is acceptable and well understood by local communities. The system uses three ICTs: (1) mobile phones; (2) wireless sensor networks; (3) fuzzy cognitive maps. This dissertation is a documentation of the complete advancement undertaken in developing the system; from its design to implementation and evaluation.

1.4 RESEARCH QUESTIONS

The principal goal of this study was to develop an adaptive pollution management prototype that integrates local with scientific knowledge for Lejweleputswa district, Free State. The following research questions were derived in achieving this goal:

Question 1:

- To what extend can an environmental pollution management system that integrates local knowledge mitigate impacts associated with pollution?

Question 2:

- To what extend can an environmental pollution management system that integrates local knowledge be acceptable by mining communities of Lejweleputswa district?

Question 3:

- How will the adoption of Fuzzy Cognitive Mapping (FCM) in the development of the system in (Question 1) above lead to a dynamic (adaptable to its environment) system?

Question 3.1:

- What is the relevance of fuzzy cognitive maps in ensuring buy-in of the system by community members?

Question 3.2:

- What is the role of fuzzy cognitive maps in ensuring dynamism (adaptable to its environment) of the system?

1.5 RESEARCH OBJECTIVES

- To examine local knowledge of the communities with regard to environmental pollution caused by mining activities and how they mitigate pollution impacts.

- To explore the usage of fuzzy cognitive maps on mapping the local knowledge of communities.
- To collect pollutants data on the area of interest using sensor nodes and compare it to quality standards.
- To develop an adaptive and acceptable mobile (Short Message Service(SMS)) based environmental management system that integrates local knowledge with wireless sensor data.

1.6 SCOPE AND CONTRIBUTION

The core contribution of this research is a framework for environmental pollution management that closes a gap between the scientific solutions and local knowledge on pollution monitoring systems. In distinction to monitoring systems that tend to provide macro-level pollution parameters and are based on costly conventional sensing equipment information dissemination, our solution uses the more cost effective, movable wireless sensor network technology to complement the old pollution monitoring stations. The framework uses mobile phone for dissemination especially for community members who are semi-literate. For the system to be applicable to mining communities in Lejweleputswa, the framework integrates local knowledge on pollution as an important and critical factor, this knowledge was analysed by fuzzy cognitive maps software. To test the framework, an integrated system prototype was developed and deployed and is accessible to members of public via a user-friendly web portal and can also be cross-examined by sending text messages from mobile phones.

The use of adaptive environmental management system has a potential of monitoring environmental pollution caused by mines has on the communities, integrating local and scientific knowledge allows the system to be more appreciated and used by locals. This solution presented here exploits the use of ICT in all stages of monitoring process; from collecting monitored parameter data, to transmitting, storing, analysing, and distributing the data to the target population. For an example, monitoring pollution is accomplished in a very cost-effective manner by making use of wireless sensor networks which includes hardware such as sensor boards, sensors, General Packet

Radio Service (GPRS) and Global Positioning System (GPS) modules that are used for parameter data collection. Again, artificial intelligence technique such as fuzzy cognitive maps has proven to be useful when it comes to computerizing local knowledge by means of mental modeller software, Creating Fuzzy Cognitive Maps (FCMs) in consultation with the community allowed communities to get a better understanding of how the whole system will work, creating concepts out of their perceptions and integrating them into the system was a much better way of getting a broader view of how the community understands their environment.

The framework consists of three components: (1) gathering of sensor and local pollution knowledge, (2) monitoring gathered data (3) dissemination of data as alerts and report.

In order to test the framework an elaborate system made up of the following three sub-systems was implemented and tested:

- Android Mobile Application to input and output local knowledge indicators as well extreme events;
- SMS Gateway that allows members of the public to interact with the entire system for sending and receiving pollution data. It is also used to receive pollution readings from sensors into the system;
- To further improve its relevance, acceptability and resilience, the framework was designed in consultation with representatives from the monitoring school in Nyakallong community. For testing of the framework, an integrated system prototype was developed and deployed and is accessible to members of public via a user-friendly web portal and can also be accessed by sending text messages from mobile phones. Furthermore, this research produced the following different contribution: being a relatively new technology in Lejweleputswa, the use of wireless sensor networks for pollution monitoring is still unfamiliar.
- Secondly, the critical role of local knowledge on pollution monitoring in building appropriate, resilient and effective pollution management system has been taken a little further in this research. We showed how the use of fuzzy cognitive maps for local knowledge is not only a better way of protecting the holism of this knowledge but also a step towards integrating it with the scientific

knowledge. To this end, this feature of our research is a unique contribution to the body of knowledge since no literature reviewed by the researcher showed the use of this two knowledge's in monitoring pollution.

- Finally, an integrated system prototype was a major deliverable of this research; this provides a way which the outside world can test the system.

1.7 STRUCTURE OF DISSERTATION

Chapter 2 – LITERATURE REVIEW: This chapter is a detailed review of the relevant (to this research) literature. This includes a detailed study of environmental pollution in terms of definitions, what causes it and the types of environmental pollution the study focused on, and a brief overview on how ICTs (Mobile phones, wireless sensor networks and fuzzy cognitive maps) can be used to mitigate pollution. A brief overview of local knowledge use on environmental pollution, this chapter also incorporates a study of integration of local and scientific knowledge. The final part of this chapter is a brief introduction to related environmental management systems.

Chapter 3 – RESEARCH METHODOLOGY AND DESIGN: This chapter describes the research methods and designs that were used in the course of this research.

Chapter 4 – SYSTEM DESIGN AND DEVELOPMENT: This chapter presents the framework architecture; analysis and design of the system as well as implementation of the system.

Chapter 5 – SYSTEM TESTING: This chapter discusses the prototype results derived from experimental tests conducted using the three sub-systems (android mobile application, SMS application and web-portal)

Chapter 6 – CONCLUSION AND FURTHER WORK: This chapter concludes on the research study as well as and discuss the path the study anticipates to take.

2. LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents literature related to the analysing of environmental pollution that is caused by gold mines around Matjhabeng municipality in the district of Lejweleputswa. The district falls among local communities that are susceptible to TB due to many mining operations in South Africa (other communities are prisoners and miners) as indicated by one Government Minister (Motsoaledi, 2014).The chapter gives details of how pollution can be monitored; this is by integrating two knowledge (local and scientific) systems. The first section of the chapter starts by defining environmental pollution and how mining contributes to it. Environmental pollution is further explained in terms of three natural resources; air, soil and water. A brief look at the recommended common natural resource parameters and their International System of Units (SI units) is also described. The larger part of the chapter discusses the role of Information and Communications Technologies (ICTs) in environmental monitoring in terms of wireless sensor networks and fuzzy cognitive maps and their specific applications in this regard. A discussion about local and scientific knowledge and their integration is also included and lastly, the chapter looks at the monitoring (water and air) systems that are currently used within the district studied.

2.2 ENVIRONMENTAL POLLUTION

2.2.1 Environmental Pollution Definition

Environmental pollution is defined as contamination of physical and biological components of the earth/atmosphere system to such an extent that normal environmental processes are adversely affected (Kemp, 1998). In addition, researchers at conserve-energy-future explains pollution as the introduction of any substance property like gases, radiation or toxic chemicals into the environment that has or results in direct harmful effects to humanity and the environment (Conserve-energy-future, 2015). Environmental pollution is responsible for making the environment less fit for its intended use. The World Health Organization (WHO) warns that environmental pollution accounts for about a quarter of illnesses affecting fauna and flora around the world, most of these environment-related illnesses are however not easily detected and may be attained during childhood and manifested later in adulthood (James, et al., 2014).

Pollution has become an environmental concern in the world; it is mostly caused by natural factors such as methane emissions from cattle or toxic materials expelled from volcanoes (Pollution Issues, 2015). Again rapid urbanization taking place around the world has led to the misuse of natural resources which ends up in nature's degradation. Human factors such as agriculture and industrial production also contribute to environmental pollution (Pathak & Mandalia, 2011). A report titled "2012 world's worst pollution" identified the top ten industries that are polluting the environment, the mining and ore processing took the third position out of ten industries (Blacksmith Institute & Green Cross Switzerland, 2013).

2.2.2 Gold Mining Waste in South Africa

A Gold mine is a place where gold is extracted, a source of wealth, valuable information, or resources (Memidex, 2013). Methods used for mining gold depend on the location, nature and scope of mineral resources (Hassan, 2011). Mining method such as "underground" produces a lot of waste that affect natural resources being discussed in this study.

As indicated in chapter 1 (section 1.1) South Africa is home to some of the deepest mines in the world.

2.2.3 Types of Pollution

There are different forms of environmental pollution; air, soil, water, light, noise, thermal and visual. This study focuses on only the first three forms, i.e. air, soil and water.

Air pollution

Air pollution occurs when air gets affected by gaseous substances, dust, fumes or odour in high volumes, which could be harmful to the health or comfort of humans, Air pollution also cause damage to fauna and flora. Air pollution in Africa is estimated to exceed the limits set by of World Health Organization by 10 to 30 times (3SMedia, 2013).

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 400km² (Bambas, et al., 2013).

Mine dumps (a large mound or hill of mining waste at the surface of a mine) are significant source of particulate matter air pollution which is a mixture of both solid and liquid particles. In this instance, mine dumps produce coarse particles/dust which have a diameter smaller than 10µm (PM10) (Martin, et al., 2014). Dust 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 (Wright, et al., 2014). This kind of dust generally comprise of heavy metals, e.g. zinc, copper, lead and arsenic which are chemicals used during the milling processes, and other toxic material including cyanide and the radioactive uranium (Rösner & van Schalkwyk, 2000). Apart from dust, mines also release greenhouse gases from the underground such as methane, and carbon dioxide into the atmosphere. These types of gases are known to be the major cause of global warming, as they trap heat in the earth's atmosphere (Kumar & Brindha, 2015).

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 restore it to open field as the mine laws dictates (Seccombe, 2014). This has decreased the number of dumps around the district, but there are still many more remaining.

Soil pollution

Soil pollution is defined as the build-up in soils of persistent toxic compounds, chemicals, salts, radioactive materials, or disease causing agents, which have adverse effects on plant growth and animal health (Ashraf, et al., 2014). Soil is considered a non-renewable natural resource, it is an important mineral for our society in protecting the environment, buffer against strong tidal waves and storm, home to shellfish species and marine organisms, used for making concrete, filling roads, building sites, brickmaking, making glass, sandpapers and reclamations (Saviour, 2012).

Heavy metals that are contained in the tailings (waste) from the mines contaminate the soil and have a very long persistence time (not biodegradable), when they find their way in the nearby lands or soil, they reduce the fertility of the soil (Abdul_Wahab & Marikar, 2011).

Acid mine drainage also alters the potential of Hydrogen (pH) of the receiving soil significantly and ultimately its fertility (Sheoran, 2010). This has resulted in loss of farmland, deforestation and forcing population to relocate from the district. Mine dumps are right next to the agricultural crops and the area that was once known for its rich maize, wheat and sunflower farming has turned into a dry place worth of nothing.

Water pollution

Water pollution is any addition of harmful chemicals to natural water that can damage living organisms or make water unfit for certain uses. Water is a crucial resource that is mostly threatened, one cannot really survive without it.

South Africa is water-scarce, further 65% of the country receiving an average annual rainfall of less than 500 mm, which is normally considered to be the minimum required for rain-fed cropping. The country also faces increasing pressure on limited freshwater sources, which are increasingly threatened by point and non-point source pollution, all of which means that new sources of water need to be sought (RoddaI, et al., 2011).

To assist in the scarcity of water, Rashidinejad and other researchers suggested that one of sustainability development plans should be to ensure uncontaminated streams, rivers, lakes and oceans (Rashidinejad, et al., 2008). This could be achieved by monitoring crucial water parameters such as potential of Hydrogen (pH) and temperature, turbidity etc.

When heavy metals emanating from mine dumps come into contact with rain or any form of water that causes the release of metals from dumps, it forms what is known as acid mine drainage and this leaks into rivers, lakes, streams or any form of water. This causes potentially long-term devastating impacts not only for human being but also for aquatic life. (Saviour, 2012).

One of the communities in Matjhabeng known as Nyakallong overlooks a mine dump and a putrid dam affected by acid mine drainage on the shores of which children play.

Guidelines for environmental pollutants and their SI Units

To accurately monitor environmental pollution, one needs to monitor an array of pollutants. In South Africa for example, the government has set the ambient air quality standards for critical pollutants to prescribe the allowable ambient concentrations of pollutants which are not to be exceeded during a specified time period in a defined area. If these standards are exceeded, poor and potential adverse health impacts are likely to occur. Even so, there are no limits nationally and internationally for CO2 and CH4. A CO2 value of 350ppm is defined as the threshold value for climate change (Bala, 2017). National Institute for Occupational Safety and Health's (NIOSH) recommended safe met CH4 concentration to be 1000ppm for 8 hours (Rim-Rukeh, 2014).

2.3 SCIENTIFIC SOLUTIONS TO ENVIRONMENTAL POLLUTION MONITORING

Environmental pollution monitoring involves the physical, chemical and biological quantification of the amount of pollutants entering the environment and the monitoring of ambient levels for trends and potential problems (Gilbert, 1987). The goals, sample collection strategies, and methods of analysis used in monitoring must be well defined in advance to obtain robust results. An understanding of the target environment, including the physical, chemical, and biological variables and processes involved is crucial during the monitoring preparation period. Some research studies seek to determine how pollutants distribute and persist in air, water, soil, and biota. Others seek to determine the effects of pollutants on man and his environment. Field and laboratory data may also be collected to study the transport of pollutants through the environment by means of food chains and aerial pathways to man and to determine and quantitate the cause-and-effect relationships that control the levels and variability of pollution concentrations over time and space.

Environmental pollution methods include surveys, surveillance, and monitoring of environmental chemicals as a part of the contribution of analytical chemistry to ecotoxicology (Gilbert, 1987). Bio-monitoring of pollution on affected organisms such as visual rating, genotoxicity rating and metabolic rating has become quite common. In monitoring pollution of the affected environment, data are principally collected at given geographical locations in the water, soil, air or biota, often described by the longitude and latitude; the depth and the time at which the sample is taken (Aighwei & Ekundayo, 2009). The frequency of sample collection is equally important. The results of the monitoring will be reviewed and analysed statistically.

The technological aspects as well as the infrastructure required are important during data collection and analysis. In recent years, environmental pollution detection and monitoring is being done by approaches involving bio-systems. For example, Environmental Protection Agencies (EPAs) consider bio-monitoring of pollution as a useful device to monitor environmental pollution from the point of diagnostic, preventive and remedial measures.

The different types of legislation, i.e. regulations, directives and acts on environmental pollution must also be considered.

2.4 RELEVANT ICTS FOR POLLUTION MONITORING

ICT is an umbrella term that includes any communication device or system encompassing, mobile phones, radio, television, computer and networking hardware and software, satellite systems, as well as the various services and applications associated with them (Khan, et al., 2015). ICTs increasing usage being witnessed today makes it the most important factor for the world to depend on for solutions to many of today's and tomorrow's problems. In this study, the focus was on the use of ICTs to curb environmental pollution. One of the ICTs that causes revolution is the mobile phone; it enables people to communicate on the go, wherever and whenever they need to. Mobile phones are now reshaping and revolutionizing the communications globally, its impact on the economic activities of nations, businesses, and small entrepreneurs is phenomenal (Ogbomo & Ogbomo, 2008). Statistics has shown that mobile phones users moved from 4.01 billion in 2013 to 4.43 billion in 2015 and it is predicted that the number will increase up to 5.07 billion users globally in 2019 (STATS SA, 2016). In developing countries, the number of mobile-broadband subscriptions continues to grow at double digit rates, reaching a penetration rate of close to 41% (ITU, 2016). This allows mobile phones to be the ideal hardware platform to disseminate any form of information to people.

The use of mobile phones has been extended from its traditional usage as mere communication devices, to computing devices with well-designed solutions on which the much needed e- applications operate on (Masinde, et al., 2013). Businesses, institutions, news (we read daily news on our phones) and so on, have embraced the use of ICTs, they now use mobile phones to perform their duties and to also reach their target market. For instance, some educational institutions use mobile phones for learning purposes; software's such as Gmail for messaging, Automatic Teller Machine (ATM) systems for easy deposit and transfer of money have made life easier for many. Software companies such as Microsoft provide the opportunity for users by using ICT to move people/organizations from traditional time consuming ways of filing, calculating, and capturing information to a more time efficient way by creating Microsoft office package (e.g.: Microsoft word for information capturing).

In terms of environmental pollution monitoring, ICTs could be exploited in all stages of monitoring and predicting process; from collecting monitored parameter data, to transmitting, storing, analysing, and distributing the data to the targeted population. For an example, monitoring pollution could be accomplished in a very cost-effective manner by making use of wireless sensor networks which includes hardware such as sensor boards, sensors, General Packet Radio Service (GPRS) and Global Positioning System (GPS) modules that can be used for parameter data collection.

Furthermore, artificial intelligence techniques such as fuzzy logic and artificial neural networks have proven to be useful when it comes to computerized information system that supports business and organizational decision-making activities called Decision Support Systems.

A wireless sensor network is a group of specialized transducers (devices that converts one form of energy to another) with a communication infrastructure for monitoring and recording conditions at diverse locations (Kaur & Garg, 2013). Commonly monitored parameters are temperature, humidity, pressure, wind direction and speed, illumination intensity, vibration intensity, sound intensity, power-line voltage, chemical concentrations, pollutant levels and vital body functions (Emary & Ramakrishna, 2013) . WSNs have gained the ground in all sectors of life with applications in a variety of fields such as environmental and habitat monitoring, healthcare monitoring of patients, weather monitoring and forecasting, homeland security surveillance, tracking of goods and manufacturing processes, safety monitoring of physical structures and construction sites, smart homes and offices, traffic control and military network systems (Manna, 2014).

The use of WSNs in developed countries has come of age; however, it is still lacking in the case of developing countries. Most districts around South Africa still depend on conventional monitoring stations rather than real–time systems such as the ones based on WSNs. This is despite of the fact that the adoption of ICTs makes it possible to move from manual and semi-mechanical systems (conventional monitoring systems) into new sensing platforms that make use of communication protocols such as ZigBee (a cost-effective, low power kind of wireless communication oriented to short distance) (Bagula , et al., 2009). Unlike traditional wireless devices, wireless sensor nodes do not need to communicate directly with the nearest high-power control tower or base station, but only with their local peers (Garg, et al., 2011).

The power of WSNs lies in the ability to deploy large number of tiny nodes that autonomously assemble and configure themselves; this could be done even in small areas such as Matjhabeng. 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, in this instance parameters such as pH and temperature level of water and soil, and PM10.

Another typical WSN deployment scenario consists of placing sensing devices into an environment to collect key physical parameters such as humidity, light intensity and temperature, and to communicate the results via an Ethernet, Wi-Fi or GPRS network to a local or remote centre (Bagula, et al., 2012).

Although Environmental monitoring can mean the monitoring of any kind of environment, it is often defined as the observation and study of natural environments (Bader, 2011). In this case, the WSNs consist of sensors that monitor pollution parameter of interest in environment. In the face of climate change, the world faces unprecedented challenges in environmental management; it would help if it was possible to automatically collect and analyse environmental data in order to avoid any potential risks (El-Bendary, et al., 2013).

One of the ideas behind WSNs is that if commercialized, they would allow people to be more proactive in monitoring pollution on daily basis. Users could for example avoid areas where the levels of pollution are dangerously high, and would perhaps be more motivated to pressure local authorities to do something about the problem. Current environmental pollution monitoring systems focus on monitoring air, soil or water pollution individually instead of combining the three as proposed by this study.

2.4.1 Mobile Phones and Web Portal

Mobile phones users increased from 4.01 billion in 2013 to 4.43 billion in 2015 and it is predicted that the number will increase up to 5.07 billion users globally in 2019 (STATS SA, 2016). Even the statistics indicated that in the district of Lejweleputswa, mobile phones percentage is higher than that of computers regardless of the model of phone (smartphones and non-smartphones). This study focuses on making use of this availability of mobile phones to disseminate environmental pollution alerts, to also allow locals to monitor pollution and report it into the system using their phones. Activities performed on our mobile phones such as communication, games can be extended to use of sustainable applications such as monitoring and prediction systems.

According to Effective Measure, instant messaging and emailing are the most commonly used activities South Africans perform on the web, accessing social media comes as the third most used activity by South Africans (Effective Measure, 2013) . The web portal, (a web site that brings information together from diverse sources in a uniform way, constructed in a way that each information source gets its dedicated area on the page for displaying information) is a useful technique to be used mostly for decision-makers who mostly spend time in the office using a computer instead of a mobile phone. It is also a good initiative because of all the additional information it will be contributing to the community.

2.4.2 Examples WSNs-Based Pollution Monitoring Systems

Air quality monitoring systems

In order to conform to the standards of an oil gas industry in China, an air quality monitoring system was developed. The system makes use of ZigBee wireless communication protocol to send pollution data to the monitoring centres so that, if some anomalies occur, a rapid warning is generated and sent to staff to remind them to take effective measures for preventing major accidents and protect human lives in industry (Wang, et al., 2011).

A Mobile Air Pollution Monitoring System was developed in Sharjah city in the Middle East, the system consists of a Mobile Data-Acquisition Unit (Mobile-DAQ) and a fixed Internet-Enabled Pollution Monitoring Server (Pollution-Server). The Mobile-DAQ unit integrates a single-chip microcontroller, air pollution sensors array, a General Packet Radio Service Modem (GPRS-Modem), and a Global Positioning System Module (GPS-Module).

The Pollution-Server is a high-end personal computer application server with Internet connectivity. The Mobile-DAQ unit gathers air pollutants levels (CO, NO2, and SO2), and packs them in a frame with the GPS physical location, time, and date. The frame is subsequently uploaded to the GPRS-Modem and transmitted to the Pollution Server via the public mobile network. The system has incorporated Google Maps to display real time pollutants, pollutants level as well as their locations only in large areas (Roseline, et al., 2013).

Water quality monitoring systems

A WSN system prototype was developed as a component of the Water Resource Governance System(WaGoSy) an innovative and integrated ICT solution which was designed to address challenges of water resources governance facing the Lake Victoria Basin in Tanzania. This prototype detected water temperature, dissolved oxygen, pH, and electrical conductivity in real-time. It made use of GPRS module residing on top of the gateway node to communicate with the cellular network and forward the Short Message Services (SMS) data to a WaGoSy system. This data was also received by relevant stakeholders in graphical and tabular formats through a web-based portal and mobile phone platforms (Faustine, et al., 2014).

An aquaculture WSN system in China was developed by Simbeye and other researchers in order to detect and control water quality parameters such as temperature, dissolved oxygen content, pH value, and water level in real-time. The sensor nodes were used to collect the mentioned water quality parameters and transmit them to the base station host computer through ZigBee wireless communication standard. In case of inconsistencies with the parameters, the relevant people receive short messages from the base station via the Global System for Mobile (GSM) module for notification (Simbeye & Feng Yang , 2014).

Soil quality monitoring systems

A soil energy consumption monitoring system was designed in China with the JN5121 wireless microprocessor as the core, which has the advantages of cost-effective and high stability. The system's responsibility was to acquire soil temperature, humidity, moisture and other data in real-time and used ZigBee communication protocol as well as GPRS for data transmission (Xi, et al., 2013)

WSN approach was used as an important step toward precision agriculture in the field of rice production. Wireless sensors monitored leaf wetness, soil moisture, soil pH, atmospheric pressure, and send the data gathered via SMS to the farmer who, for instance, will be able to use the information to determine the precise amount of fertilizer needed for his crops (Sakthipriya, 2014).

2.5 FUZZY COGNITIVE MAPS (FCMs)

Creating fuzzy cognitive maps (FCMs) in consultation with the community allows communities to get a better understanding of how the whole system will work. 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 combines cognitive maps with fuzzy logic, it is used to represent knowledge of complex systems characterized by ambiguity and complex processes (Kosko, 1986). A Cognitive Map (CM) is a directed graph where the nodes represent notions and its edges represents causal relations, notions are states or conditions and edges are actions or transfer functions, which transform a state in a node to another one in another node (Vascák, 2012). Additionally, CMs represent beliefs (knowledge) which are laid out about a given domain of interest and are useful as a means of decision support (Mwagha & Masinde, 2015). Fuzzy logic, a branch of Artificial Intelligence, is a processing technique which allows computers and other intelligent devices to make sense out of vague or incomplete inputs unlike the Boolean logic that recognizes statements as only "true," or "false". As represented in most digital computers, fuzzy logic is capable of expressing the linguistic variables such as "sort of true," "maybe false," or "ok."; it allows computers to more closely parallel the way humans think, identify and solve real world problems. Fuzzy cognitive mapping has proven efficient for solving problems in which a number of decision and uncontrollable variables are causally interconnected (Ozesmi & Ozesmi, 2003).

FCMs are a useful scientific approach that is used to build a model that measures the individual knowledge of local community members. This method is helpful both in obtaining the support of the local community members and to comparing the similarities and differences among groups of local community members (Ozesmi & Ozesmi, 2003). They have been applied in different areas to express the dynamic behaviour of a set of related concepts; as they can model imprecise data and nonlinear functions of arbitrary complexity and that they are based on natural language (Mwagha & Masinde, 2015). These maps are powerful tools for analysis and generate simulations in dynamic systems (Barón, et al., 2015) .They may also make it easier for the groups to make decisions together and accept the results. Some of the reasons for adopting FCMs are: ease of use, easy to construct, flexibility in representation as more concepts/phenomena can be added and interact), low time performing, easily understandable/transparent to non-experts and untrained people (Papageorgiou , 2011).

Using fuzzy cognitive maps to validate the usefulness of local knowledge on environmental pollution around communities contributes to environmental sustainability research, additionally it contributes to goal 11 "SUSTAINABLE CITIES AND COMMUNITIES" of 17 sustainable development goals developed by UN General Assembly's Open Working Group on Sustainable Development Goals (SDGs) to transform our world (UNDESA, 2016). It also allows for other research with complex or misunderstood phenomenon to be analysed, interpreted and validated. The ability of FCM to create and produce scenarios to predict based on changes made to the concepts opens up the platform to integrate this local knowledge with scientific systems that actually monitor environmental pollution in the current times.

Fuzzy cognitive mapping approach is a symbolic representation for the description and modelling of complex systems that work on the opinions of experts. FCMs model the world as a collection of classes and causal relations between classes or they describe different aspects of the behaviour of a complex system in terms of concepts (Papageorgiou , 2011). Each concept represents a state or a characteristic of the system and interacts with each other showing the dynamics of the system, they are fuzzy signed directed graphs with feedback, consisting of nodes and weighted arcs (Stylios & Groumpos, 1999). Nodes of the graph stand for the concepts that are used to describe the behaviour of the system, connected by signed and weighted arcs representing the causal relationships that exist between the concepts.

2.5.1 FCM Design

FCMs are created by experts of the system; to retrieve this knowledge from the experts, different methods are being used. Experts can be interviewed and then the recording of interviews transmitted into FCMs by someone with experience of maps creations. Again questionnaires can be used to get knowledge from the experts then transmitted into FCMs. Another solution is letting experts create their own FCMs once they understand the information or training on FCMs development that would be provided by a person familiar to FCMs. Individual maps are integrated to form one large FCM that would represent the complex system by all participated experts. The two advantages of integrating experts' FCMs are that: the integrated FCM allows expansion by incorporating new knowledge embodied in other FCMs; secondly it facilitates the construction of a relatively bias-free FCM by merging different FCMs representing belief systems of a number of experts in the same problem domain (Khan, et al., 1987). FCMs are recorded in a form of matrices of relations between them, after formation of matrices the dynamism of fuzzy cognitive maps is shown by formation of different scenarios and observing the simulation as different predictions come up according to scenarios (Mwagha & Masinde, 2015).

2.5.2 FCM Application on Adaptive/Dynamic Systems

FCMs were originally proposed as a means of explaining political decision making processes, even so they can also be made with local people, who often have quite a detailed understanding of the environment (Ozesmi & Ozesmi, 2003). The input of local people serves as an important factor when making decisions regarding the environment. This makes it easy for them to accept or adapt to changes made or chosen solutions taken for improvements.

In the case of the local people's analysis of environmental modelling and monitoring, FCMs have found a good number of applications in the world. Firstly, FCM was applied as a tool to define management objectives for complex ecosystems, multivariate statistics was used to construct and output FCMs, it was for Lake Erie watershed (Hobbs , et al., 2002). Use of the FCM method in this case promoted constructive interaction among dozens of scientists, managers, and the public, as well as providing insights concerning the potential effects of broad classes of management actions upon the Lake Erie ecosystem. A multi-step FCM and participatory approach of Stakeholder Group Analysis was proposed in Uluabat Lake, Turkey, for observation of the ecosystem (Ozesmi & Ozesmi, 2003). The multi-step fuzzy cognitive mapping approach analyses how people perceive a system, and compare and contrasts the perceptions of different people or groups of stakeholders (Vanwindekens , et al., 2013). FCMs have been employed in a number of studies including a recent study for predicting election results in India, this was achieved by calculating the percentage chances for a winning candidate, in this study FCM was used with fuzzy logic (Singh, et al., 2013). FCMs were also tested for scientifically verifying weather lore's (knowledge) received from farmers in some parts of South Africa as well as Kenya for drought forecasting (Mwagha & Masinde, 2015).

2.6 LOCAL KNOWLEDGE ON ENVIRONMENTAL POLLUTION

Local knowledge is described as knowledge that people in a given community have developed over time, and continue to develop; it is based on experience, often tested over centuries of use, adapted to the local culture and environment, embedded in community practices, institutions, relationships and rituals, held by individuals or communities and it is dynamic and ever changing (Singh & Devine, 2013).

Local Knowledge is much more than a collection of facts; it relates to the whole system of concepts, beliefs and perceptions that people hold about the world around them. This includes the way people observe and measure what is around them, how they set about solving problems, and how they validate new information (Warburton & Martin, 1999). It also includes the process whereby knowledge is generated, stored, applied and transmitted to others (Warburton & Martin, 1999).

Local knowledge is crucial when it comes to having a sustainable world, everyone's input and participation is required to come up with better decisions regarding their environment. People's perceptions of and attitudes towards climate change, drought or environmental pollution is critical for reducing exposure among people and can also influence the response to interventions that are aimed at encouraging behaviour change (Muindi, et al., 2014). This knowledge helps to ensure that policy and communication frameworks achieve change in public attitudes, thereby acknowledging the importance of the understanding that people have about the environment. People recognize that not all pollution can be experienced by the senses; therefore, perceptual indications are taken from the environment (Vissers, 2010).

People living in and around Nyakallong community are all affected by mining activities (that cause pollution); directly or indirectly. They tend to look at seasons of the year like when it is windy they know dust will be blown from mine dumps towards their homes; they also know that when it is rains, acid mine drainage affects their water, and soil fertility, Acid Mine Drainage (AMD) also releases a certain smell. Additionally, if a mine is abandoned and not rehabilitated, water left in mine shafts is bound to affect their water. All these end up affecting their health, so they have had to learn to come up with mitigation techniques such as; e.g. boiling water as it is believed to lower acidity.

2.7 INTEGRATION OF LOCAL AND SCIENTIFIC KNOWLEDGE

In order 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 (Olsson & Folke, 2001). This kind of approach has to recognise the need to integrate knowledge held by academic researchers (often across traditional academic disciplinary boundaries) and non-academic participants, such as land managers and the public, There is need to build on diverse and sometimes unrelated knowledge’s to address a research or applied question by developing shared theory, methods and new knowledge to promote common understanding of environmental management problems (Raymond, et al., 2010). Local knowledge has often played a role in the development of modern science and will continue to do so in the future; this can be seen in the development of theories, research designs, methods, and understandings employed by scientists (Nakashima & Elias, 2002). This study aimed at combining two worlds that initially stood on their own (local and scientific knowledge) in the hope that the two will counterbalance each other's weaknesses, resulting in some kind of hybrid knowledge that will be critical for promoting sustainable environment, and also to create an adaptive system that could be acceptable and understood by local communities. An adaptive system involves combining, in a dynamic on-going process, local and scientific knowledge in the co-management of resources and ecosystems publicizing that knowledge in a well understood manner by the communities involved (Olsson & Folke, 2001).

The scientific approach is mostly known to the more developed communities with ease of access and understanding of tools such as smartphones, internet or computer. Mining communities in Matjhabeng municipality do not really have access to such tools and their understanding of science is limited. So in order to monitor pollution, the locals tend to depend on their own local knowledge. Though this method has worked for the communities, its integration with scientific knowledge can be used to solve some of the complex environmental challenges; further it will give the local knowledge platform to be recognized and adopted by other communities or the country based on the its usefulness and contribution.

There are many different perspectives of what constitutes knowledge or how someone comes to know something. This creates confusion and misunderstanding when attempting to integrating different forms of knowledge. Integrating the two knowledge systems is however important because it brings the sense of ownership to the locals and it makes the system adaptable to change in the mining communities. Integrating the two knowledge' systems and disseminating its information to locals, using SMSes is advantageous since majority of the mining community members are elderly (and sometimes illiterate) people who do not have smartphones and access to the internet, but for other individuals with smartphones and internet access, an android mobile application and a web portal are available. Statistics indicate that 69, 8% of the Matjhabeng municipality's (Nyakallong forms part of this municipality) population have no internet access, 89, 6% own cell phones, 18,4% own computers, 81,5% have televisions and 75,1% have radio access (STATS SA, 2017).

Literature is awash with examples that demonstrate that integrating scientific and local knowledge is useful. One system that was developed for the south eastern part of Nigeria and named Integrated Toposequence Analysis (ITA), incorporates the villagers' evaluation of their environment and the dynamics of cropping systems into conventional bio-physical transect descriptions. ITA thus provided an integrated approach for characterising toposequences and analysing current problems and possible future trends concerning land management at toposequence level. It also sets a framework for developing relational databases for land resource mapping and exploring priorities and opportunities for certain land use and cropping systems (Gobin , et al., 1998).

Another recent example includes the Multiple Evidence Base(MEB) which is an approach that proposed equivalents; that is indigenous, local and scientific knowledge systems are viewed to generate different indexes of knowledge, which can generate new insights and innovations through complementarities. MEB emphasizes that evaluation of knowledge occurs primarily within rather than across knowledge systems. MEB, on a particular issue, creates an enriched picture of understanding, for triangulation and joint assessment of knowledge, and a starting point for further knowledge generation (Tengo , et al., 2014).

2.8 RELATED ENVIRONMENTAL MONITORING SYSTEMS

Below are details of some of the existing environmental monitoring systems currently in use in both South Africa and elsewhere in the world.

2.8.1 South African Air Quality Information System for Monitoring Air Quality

One of the monitoring systems being used in the country for monitoring air quality for all provinces and their districts is the South African Air Quality Information System (SAAQIS) that was established by Department of Environmental Affairs (DEA). The system is hosted by the South African Weather Service (SAWS) (Mdluli, 2014). SAAQIS is divided into segments: the first segment is the ambient air quality, which is also an information source of air quality management documents for the government. This functionality includes interactive maps that may be zoomed into for more detail (metadata) on the ambient-air-quality-monitoring stations that are feeding information into the system, including location, photographs of the stations, sources and types of pollutants being monitored (Van Wyngaardt, 2011). There are over a hundred monitoring stations in the country which report ambient air quality monitoring data to the SAAQIS and this allows all stakeholders, such as government officials and the community members, to access verified data showing the state of air quality at any given point in time (Mdluli, 2014). Currently, there are no conventional monitoring stations in the district of Lejweleputswa that are able to gather pollution data for distribution to SAAQIS; this implies that pollution data from the district is simply an estimation that is computed using data collected by stations from other parts of the

Free State province. This introduces huge errors to the readings of the pollution data for the district, hence, the data is of little use and is unavailable most of the time (tested by researcher).

2.8.2 Blue Drop System for Water Monitoring

The national Government has implemented regulations and policies to deliver safe water to all; some local municipalities however, are yet to adhere to these national guidelines (Rivett, et al., 2013). This is particularly true for mining communities and municipalities with structures where water supply is only partially reticulated and treated. The low compliance rate is generally explained using reasons such as under-resourcing, skill shortage and lack of understanding of required standards. Other excuses include: lack of intervention to address problem areas, inadequate management, and limitations on finances, assets and fiscal accountability (DWA, 2012).

Water Service Authorities, which are either municipalities or district municipalities, are required to submit information regarding water quality regularly to the national Blue Drop System (BDS) (Rivett, et al., 2013). The BDS is a website that can be accessed by the public to look up water quality information that was provided by municipalities.

2.8.3 Monitoring School

The communities of Lejweleputswa have come up with ways to monitor the environmental pollution; to this end, there is a community monitoring school that was developed by the Bench Marks Foundation and work with an organization called Gold and Uranium Impact Censoring Organization. The school is mobile and rotates around the district but mostly it runs around Nyakallong and Welkom The school deals with issues affecting the communities including mining by making contacts with the responsible policy makers, writing newsletters and making podcasts or protests and mobilizations to make their voices heard.

2.9 SYSTEM ARCHITECTURE

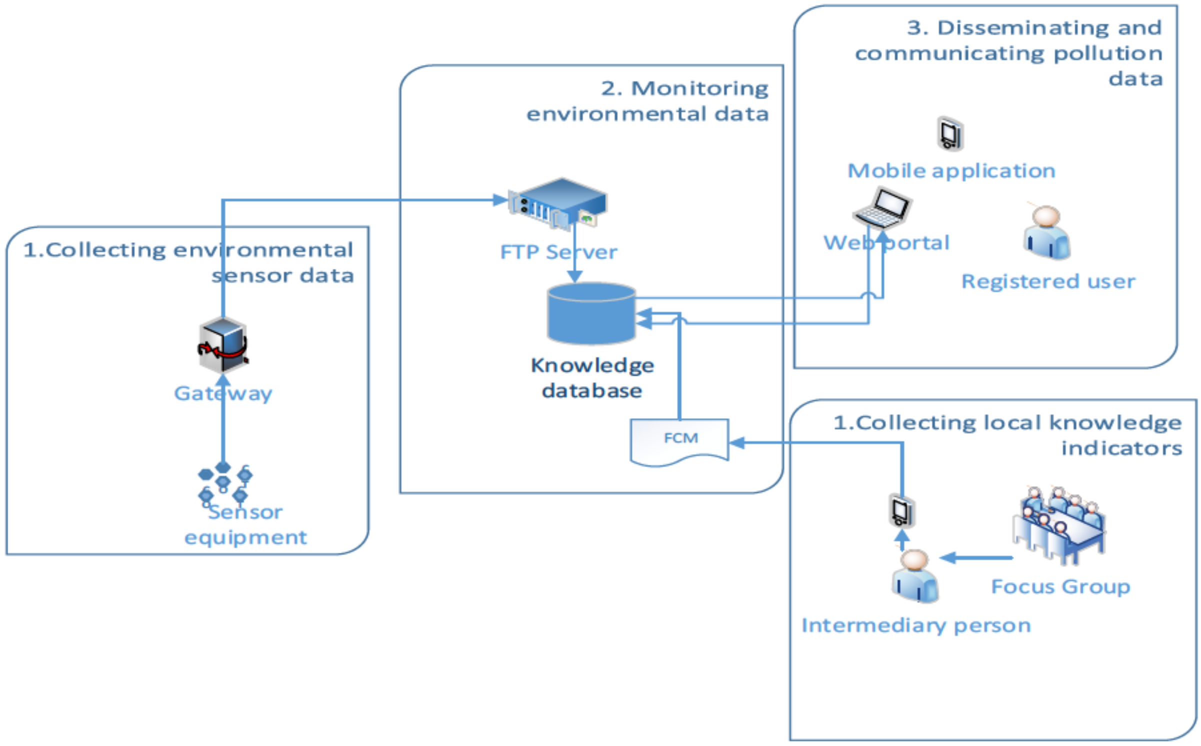

Figure 2.1 ***Conceptual Framework***

1. **Collecting environmental sensor data and local knowledge indicators:**
   a. Sensor nodes collect and transfer monitored parameter's data to the gateway, the gateway transfers collected data to File Transfer Protocol (FTP) server since the server allows for file sharing over an Internet connection to and from users. Not only can FTP handle multiple files in the same transfer, but it has also proven itself adept at allowing for large file transfers as well. From the server data moves to the database for monitoring and storage.
   b. Focus groups are made up of 10 local knowledge experts and meet regularly to discuss various environmental pollution indicators. An intermediary person with understanding of local and scientific knowledges from the community sits in to note down indicators for integration with the monitoring system. Once an agreement on indicators is reached, the indicators are keyed in to the mobile phone for storage. The indicators are

stored on local SQLite database then later transferred to MySQL database when network connection becomes available.

2. Monitoring environmental data: local knowledge is analysed by FCM; all this information is stored back to database.

3. Disseminating and communicating environmental data: Desktop application is able to send alerts to the community members about extreme pollution events around them, effects associated with the indicators as well as level of WSN parameters.

Intermediary person makes use of the mobile application in order to monitor pollution using local knowledge; they can also send extreme events, alerts into the system. A web portal displays pollution related information to the end users as well as allow the users to discuss about pollution using the discussion board.

3. RESEARCH METHODOLOGY

3.1 INTRODUCTION

All research is based on some underlying theoretical expectations about what establishes ‘concrete’ research and which research method(s) is/are appropriate for the development of knowledge in a given study. For conducting and evaluation of any research, it is important to know what these expectations are. As it is indicated in the title, this chapter includes the research methodology of the dissertation. When talking about “research methodology” we refer to a systematic way to solve a problem, a science of studying how research is to be carried out, the procedures by which researchers go about their work of describing, explaining and predicting phenomena (Rajasekar, et al., 2006). Research methodology consist of two phrases: “research” and “methodology”, according to oxford dictionary, research means a systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions. Research encourages individuals to explore possibilities, understand existing issues, and to disclose truths and fictions. Without research, technological advancement and other developments could have remained a fantasy.” *Curiosity may kill not just the cat, but the human as well. Yet, it is the same curiosity that fuels the mind to seek for answers*” (Zarah, 2017). Methodology is a system of methods and principles used in a particular discipline or the branch of philosophy concerned with the science of method and procedure. Methodology may include publication research, interviews, surveys and other research techniques, and could include both present and historical information.

3.2 RESEARCH APPROACH

The choice of a research approach depends on the nature of the research study. Basically, all research approaches can be classified into three categories: exploratory, causal and descriptive (Mabuda, et al., 2008).

The aim of exploratory research is to discover ideas and insight. An exploratory research is a way of clarifying ambiguous situations or discovering ideas that may be a potential business opportunity, it is not intended to provide conclusive evidence from which to determine a particular course of action (Zikmund, et al., 2013). This kind of approach can come in two forms such as a new topic or new angle. A new topic is often unexpected and startling in its findings and a new angle can come from new ways of looking at things, either from a theoretical perspective or a new way of measuring something (Study.com, 2017). The purpose of causal research is to offer explanations hence it is also known as explanatory research. The descriptive research approach is a basic research method that examines the situation, as it exists in its current state. It involves identification of attributes of a particular phenomenon based on an observational basis, or the exploration of correlation between two or more phenomena (Williams, 2007).

In this research, exploratory research approach was adopted due to the nature of the study. This approach was deemed applicable because it investigates the research questions and it is applied to get a firm understanding of the target respondent(s) knowledge, opinions and behaviour associated with the study. It seeks to know attitudes, viewpoints and preferences that people have about indicators of environmental pollution, in order to make decisions. When used properly, exploratory research provides rich quality information that helps identify the main issues that should be addressed in our research design and significantly reduce a research project's level of bias (Penwarden, 2014).

3.3 RESEARCH DESIGN

Research design is the determination and statement of the general research approach or strategy adopted for the particular development, it is the heart of planning. If the design adheres to the research objective, it will ensure that the user's needs will be adhered to. Guided by objectives in chapter 1, one of the designs deemed appropriate for this research was a focus group consisting of individuals who allowed for the understanding of local knowledge regarding the environmental pollution by mining activities as well as providing the knowledge on effects and practices used to mitigate or prevent this kind of pollution. Focus group is a type of in-depth interview accomplished in a group, whose meetings present characteristics defined with respect to the proposal, size, composition, and interview procedures, focus or object of analysis is the interaction inside the group and participants influence each other through their answers to the ideas and contributions during the discussion (Freitas, et al., 1998).

The case study methodology was used with purposive sampling technique to recruit locals from Nyakallong community in Lejweleputswa of South Africa for this study. Since environmental pollution affects every person's daily activities, the preliminary study considered the local people from this mining community. The locals recruited and participated in this study were only from the monitoring school mentioned in Chapter 2 (section 2.8.2). The opinions of local people were considered important because they indicate how their daily lives are impacted by pollution.

Members of the focus group were asked to state their perceptions on the degree of causal effect (strong positive, positive, none, negative and strong negative) of environmental pollution indicators to expected outcomes for air (dust, outdoor temperature, house cracks, gaseous smell, acid in water and land degradation), soil (soil acids, soil temperature, salt in soil, soil fertility, plant life and soil moisture), water(acid in water, water temperature, salt in water, wild life and human health, plant life and smell). Mental Modeler software was used for analysis of these indicators.

A prototype was developed and experimental design was applied for testing it in order to provide more solid basis for decisions than intangible description or design of the system, this design is illustrated in chapter 5.

3.4 DATA GATHERING

Exploratory research allows for researcher and users to co-operate closely. Interviews within the monitoring school allowed for the researcher to collect information on the crucial local knowledge indicators the community use to observe pollution. All 30 members of the school were interviewed, an excerpt of interview question can be found in Appendices (Appendix 1 preliminary investigation questions). Questionnaires were issued to only 10 members of the focus group who were selected from the monitoring school based on the relevancy and deeper understanding of the community and local knowledge after conducting interviews. the reason behind this was to gather background data, understand the impact of environmental pollution by mining activities as well acquire user's insight about the prototype.

3.5 COLLECTION OF LOCAL KNOWLEDGE

This research aimed at investigating the relations between visual mining activities concepts and to examine their computational applicability in imitating human sense and decision making. To achieve this objective, this research investigated the most significant mine pollution concepts that are used by locals in order to determine how to carry on with their daily lives. For the research process the group was informed that the right of ownership of the information collected from them is held in trust by the researcher. The focus group completed consent forms (see consent form in appendix as part of the questionnaire) that identified the specifics of this research including the purpose and the use of the resulting knowledge.

The group participated in the interview voluntarily and had power to decide to withdraw or not to answer parts of research questions. In understanding the indicators used by the community for mine pollution observation and its impacts. A pilot questionnaire was designed (with various visual air, soil and water pollutants concepts derived from preliminary investigation) and administered at the pilot location in February 2016. The group described causal relationships between visual air, soil and water concepts (indicators) to expected pollution outcomes. This questionnaire was given to a group of 10 individuals who represented the population of Nyakallong. As stated in section 3.4, the group comprised only of students from the monitoring school of Lejweleputswa who deal with impacts of mine activities around their communities and have a better understanding of local knowledge.

In order to derive common knowledge, the data was analysed using quantitative (percentage of respondents). The final analysis was done using an FCM software called Mental Modeler. The final summarized FCM is represented in chapter 4.

3.6 DESCRIPTION OF THE STUDY AREA

Figure 3.1 L*ocal Municipalities Forming Lejweleputswa District*

This research was carried out in Nyakallong Allanridge which forms part of Matjhabeng Municipality from Lejweleputsa district. Lejweleputswa is one of the 5 districts (Fezile Dabi, Thabo Mofutsanyane, Mangaung and Xhariep) in Free State province, South Africa. The district has the second-largest (24.3%) area in the province and consists of five Local Municipalities, namely Masilonyana, Matjhabeng, Nala, Tokologo and Tswelopele (handbook, 2014). Allanridge (Nyakallong), located in Matjhabeng was named after Allan Roberts whose borehole's proximity to the gold bearing reef was the precursor to mining in the area (STATS SA, 2017) . Matjhabeng was designed for the gold-mining community.

3.7 FINDINGS

To better understand the impact that mining activities have on the community in terms of environmental pollution, a questionnaire was designed to establish the magnitude of this impact. This questionnaire was also used to collect demographic information

This section of the dissertation is intended to present findings from data that was collect from the focus group members.

Herein quantitative results are presented in form of graphs and shows in percentage terms the level of user's opinions. A copy of the questionnaire used in this study can be found under Appendices (Questionnaire 1-15).

3.7.1 Demographics of Respondents

The gender dispersal of the focus group was 40% male and 60% female.

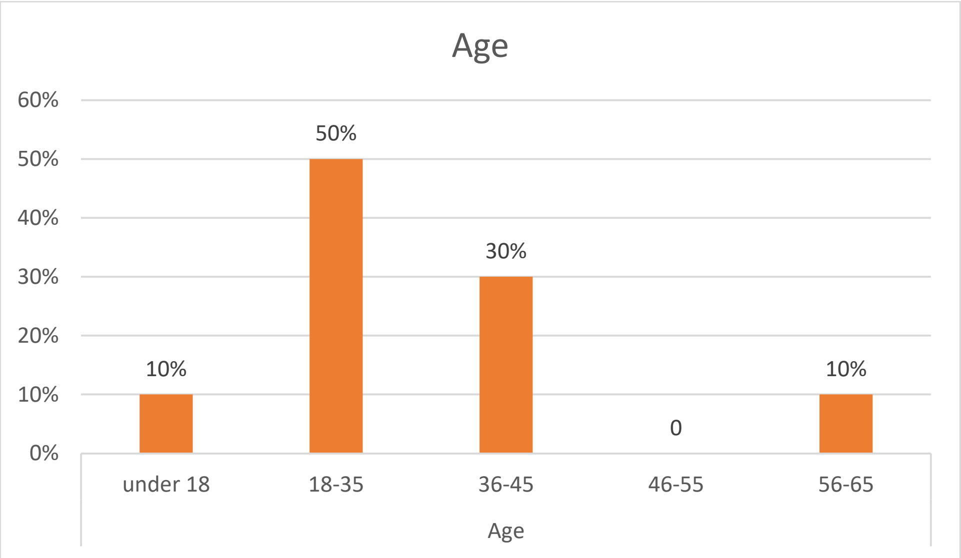

Figure 3.2 ***Age of Respondents***

On Fig.3.2, half of the respondent(s) were between 18 and 35 years of age with 50% while 30% of the respondent(s) were over 35 years, the other 10% was above 56 years another 10% was below 18 years.

The main economic activity in the community is mining represented by 100% of the respondent(s).

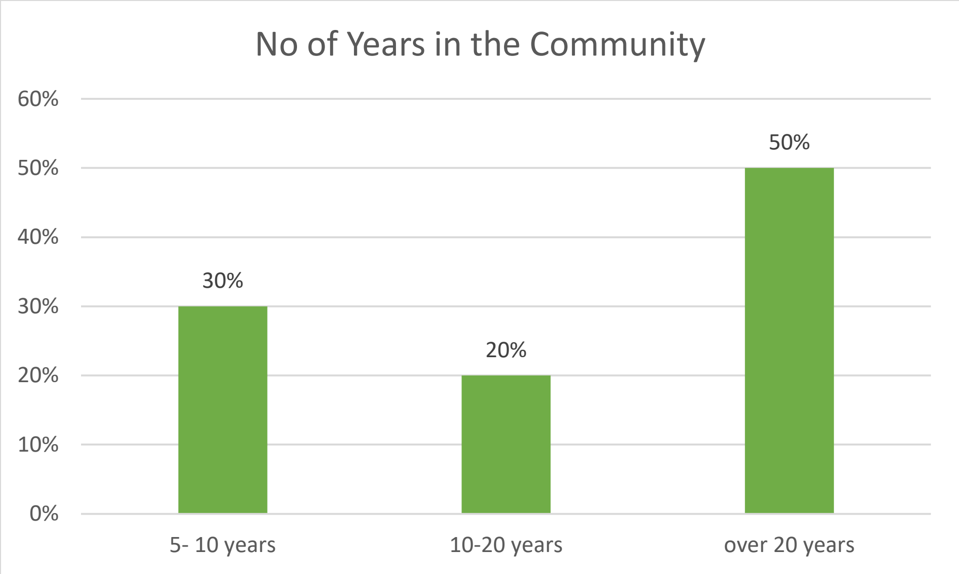

Figure 3.3 ***No of Years in the Community***

Most of the respondent(s) have stayed for long in Nyakallong, with 50% indicating that they had stayed for over 20 years of which over 30% of these have stayed for over 5 years and the remaining 20% have stayed over 10 years as indicated by Fig.3.3. All the participate(s) have been part of the monitoring school for more than 5 years.

3.7.2 Significance of Learning About Environmental Pollution

The respondent(s) were asked to provide their opinion on how mine pollution affects their daily activities. 100% of the respondent(s) stated that mine activities do affect their daily activities.

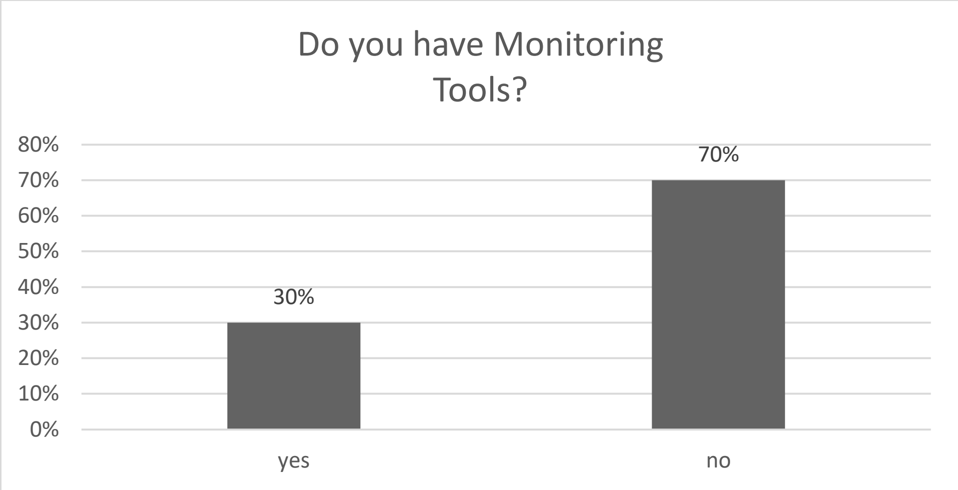

Figure 3.4 ***Monitoring Tools Availability***

As shown by Fig.3.4, majority from the group indicated that they do not have any tools to monitor this pollution while 30% indicated that they use pH stripes to monitor water pH.

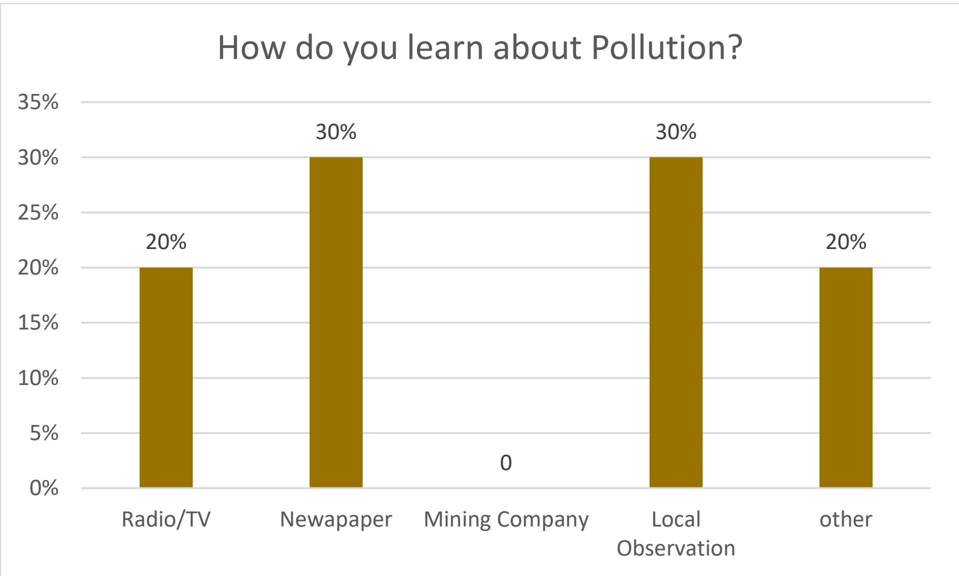

Figure 3.5 ***Learning about Environmental Pollution***

In Fig.3.5, 30% of the respondent(s) stated that they learn about mine pollution on the newspaper. Furthermore, 30% of respondent(s) indicated that they rely on local observations "other" option represents participates who learn about pollution from the monitoring school, they learn from the individuals who have observed pollution using their local knowledge.

Minority of the respondent(s) (30%) showed some confidence in their methods of learning about mine pollution, while 70% having little confidence in these methods.

3.7.3 Knowledge of Air, Soil and Water Pollution Indicators

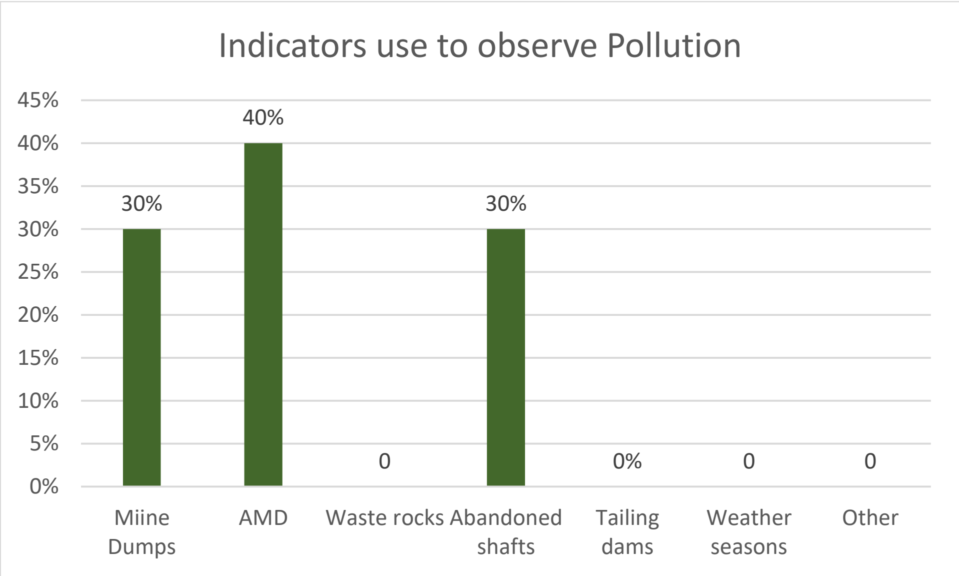

Figure 3.6 ***Indicators used to Monitor Pollution***

As shown in Fig.3.6, the respondent(s) were asked to state their knowledge and significance of the visual pollution indicators. When asked to indicate indicators they knew most, 40% of the group selected acid mine drainage as an indicator, 30% knew mine dumps, another 30% abandoned mine shafts.

About 100% of the group indicated that very often the indicators help them predict and monitor mine pollution.

3.7.4 Impacts of Mine Activities On Air, Soil and Water

The following figures demonstrates how mine activities impact air, soil and water around the Nyakallong. The graphical figures below demonstrate impacts mine activities has on water, soil and air. The “titles” on these figures represents concepts and the causal effect (increases much, increases, no effect, decreases, decreases much) they have on each other. This data was analysed by mental modeler (Mental Modeler is modelling software found at www.mentalmodeler.org that helps individuals and communities capture their knowledge in a standardized format that can be used for scenario analysis) as shown in the figures 3.12, 3.17 and 3.21. Concepts included in the model have positive (high (+++), medium (++), or low (+)), negative (high (---), medium (--), or low (-)) or no (no relationship defined) edge relationships, these edge relationships are derived from the respondent(s) feedback based on the highest percentage Figure 3.13, 3.18 and 3.22 represents the matrix interface which lists all concepts included in the FCM model on the i and j axes and translates the amount and direction of edge relationships defined in the FCM model into quantitative values between +1 and -1.(+1 means increases much, 0.5 means increases, -1 means decreases much and -0.5 means decreases were as no value means no effect).

Impacts of mine activities on water

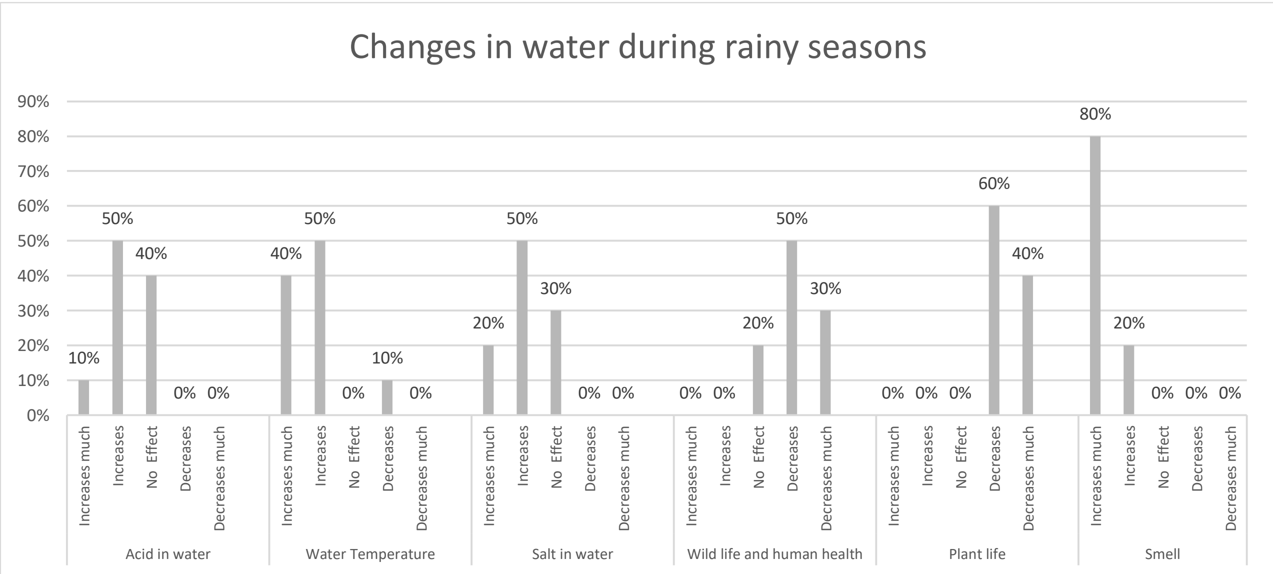

Figure 3.7 ***Changes Happening in Water During Rainy Season***

Fig.3.7 represents changes happening to water streams around the community during rainy seasons, it was indicated by 60% of the participants that plant life decreases as a result of having heavy metals leaching from mine dumps into water. Again 80% of the participants indicated that there is a foul smell coming from the dams near them.

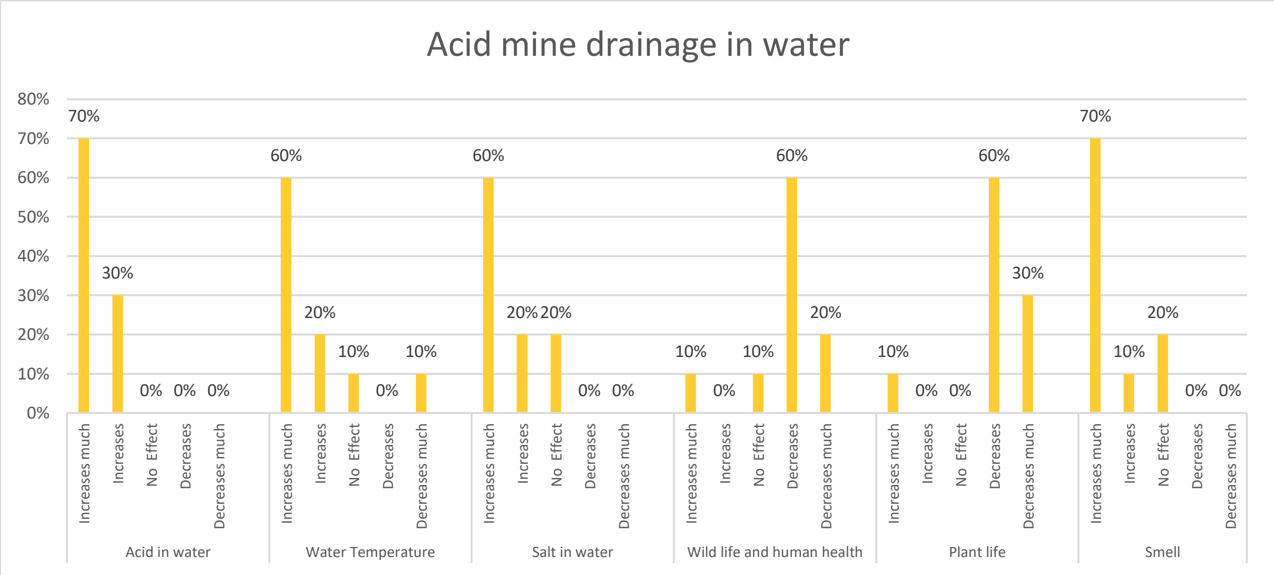

Figure 3.8 ***Contents of AMD in Water***

Fig.3.8 indicates how “acid mine drainage” affects water streams, about 70% of the participants said that “acid in water” increases much and 60% said that “wild life and health” of locals deteriorates.

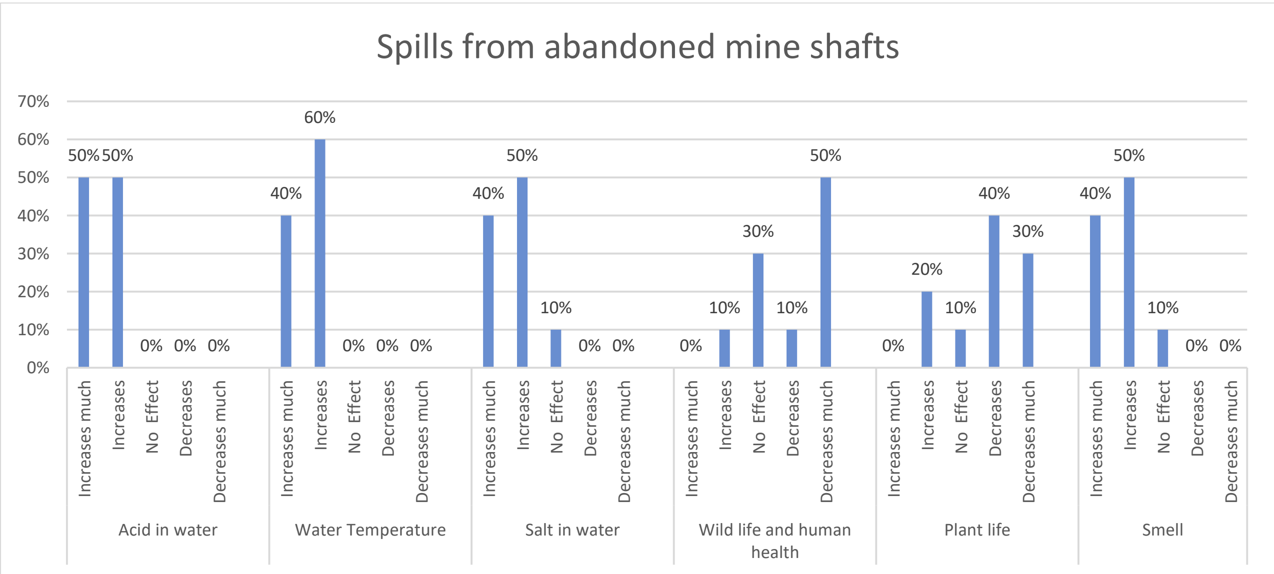

Figure 3.9 ***Spills from Abandoned Mine Shafts***

Fig.3.9 demonstrates how waste left inside “abandoned mine shafts” affect the water, about 50% of the participants said the water becomes acidic and 60% said the “water temperature” changes.

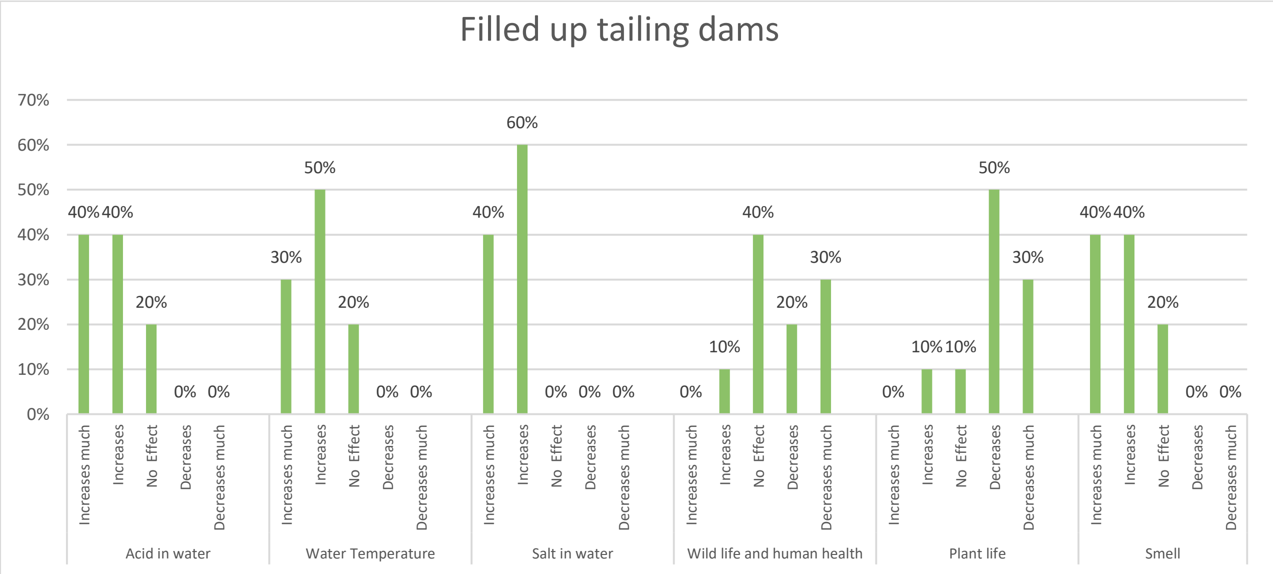

Figure 3.10 Filled *up Tailing Dams*

Fig.3.10 indicates how water from “*tailing dams*” affect dams around the community, about 60% of the participants indicated that water becomes salty and 50% said “*plant life”* deteriorates.

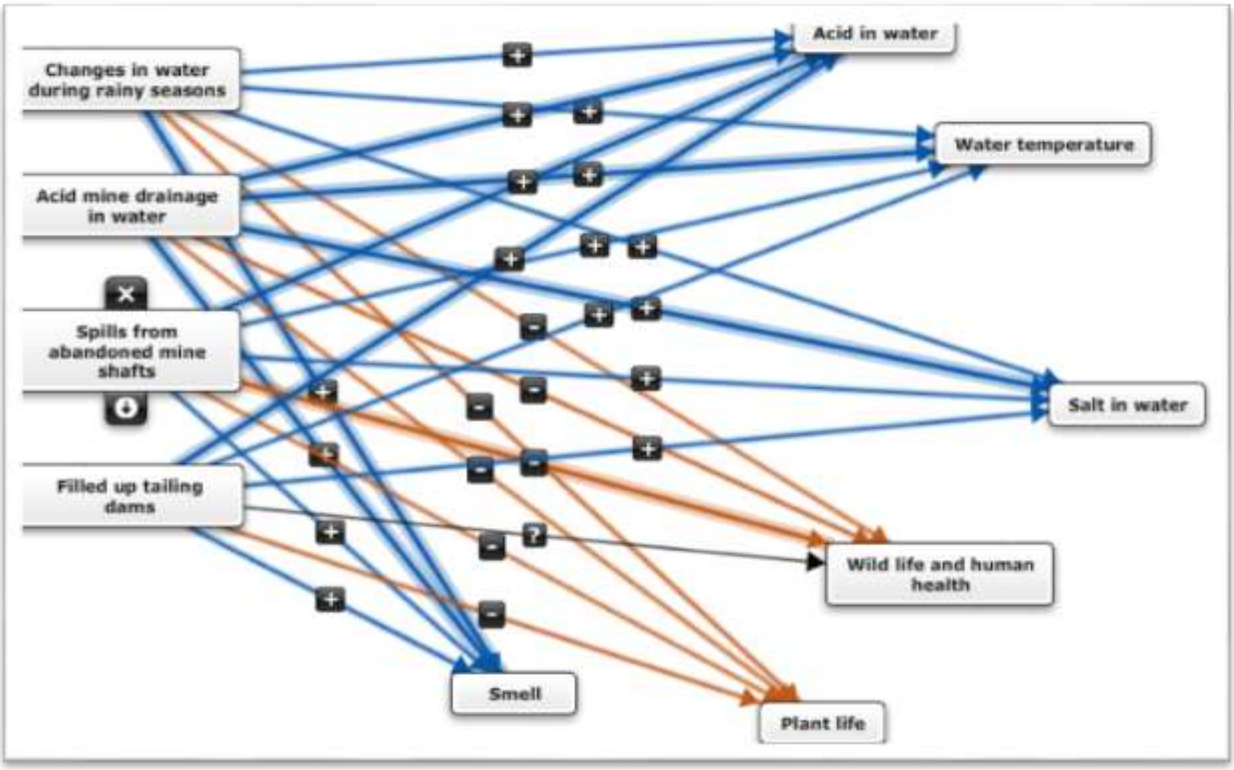

Figure 3.11 ***FCM for Water Indicators and Causal Effects***

Fig.3.11 indicates how water indicators affect one another. Like "*acid mine drainage*" increases "*acid in water*" and decreases "*wildlife and human health*".

	Changes in water during rainy seasons	Acid in water	Salt in water	Wild life and human health	Plant life	Smell	Acid mine drainage in water	Spills from abandoned mine shafts	Filled up tailing dams	Water temperature
Changes in water during rainy seasons		0.5	0.5	-0.5	-0.5	1				0.5
Acid in water										
Salt in water										
Wild life and human health										
Plant life										
Smell										
Acid mine drainage in water		1	1	-0.5	-0.5	1				1
Spills from abandoned mine shafts		1	0.5	-1	-0.5	0.5				0.5
Filled up tailing dams		1	0.5	0	-0.5	1				0.5
Water temperature										

Figure 3.12 ***FCM Matrix for Water Indicators and Causal Effects***

Fig.3.12 represents matrix of water indicators, as elaborated in section 3.6.5 above about how the causal effects work, in this matrix "*changes in water during rainy seasons"* increases acid in water (0.5) and "*smell*" increases much (1).

Impact of mine activities on soil

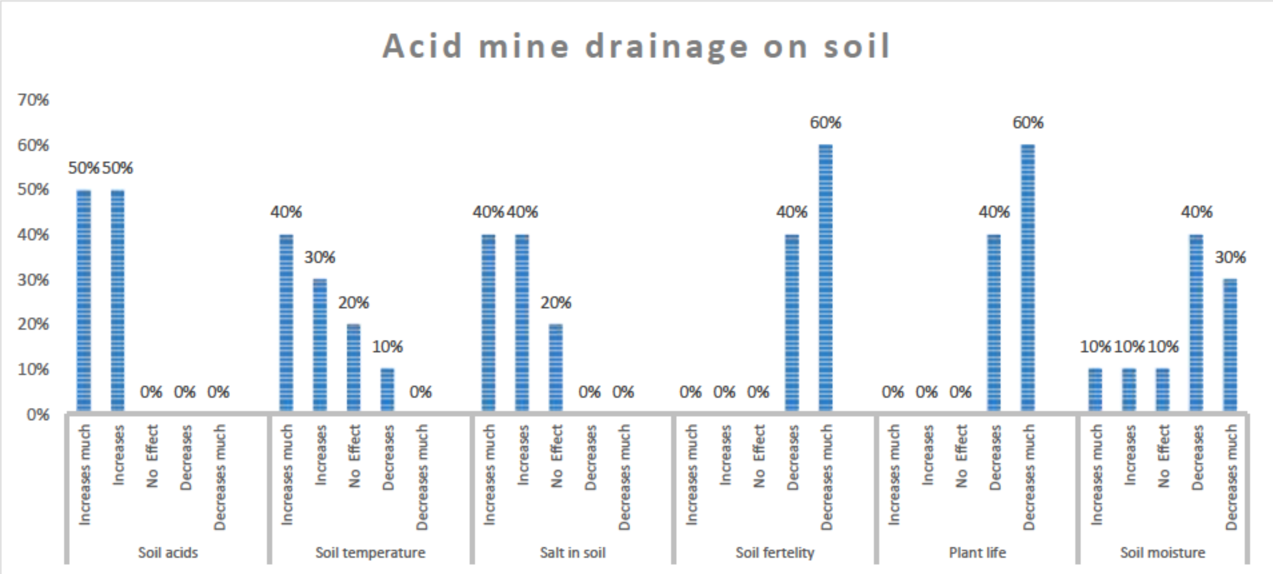

Figure 3.13 ***Acid Mine Drainage Impact on Soil***

Fig.3.13 demonstrates how acid mine drainage affect soil around the community, about 60% of the participants said "*soil fertility* "decreases much making it difficult to grow crops and 60% also said "*plant life*" decreases much.

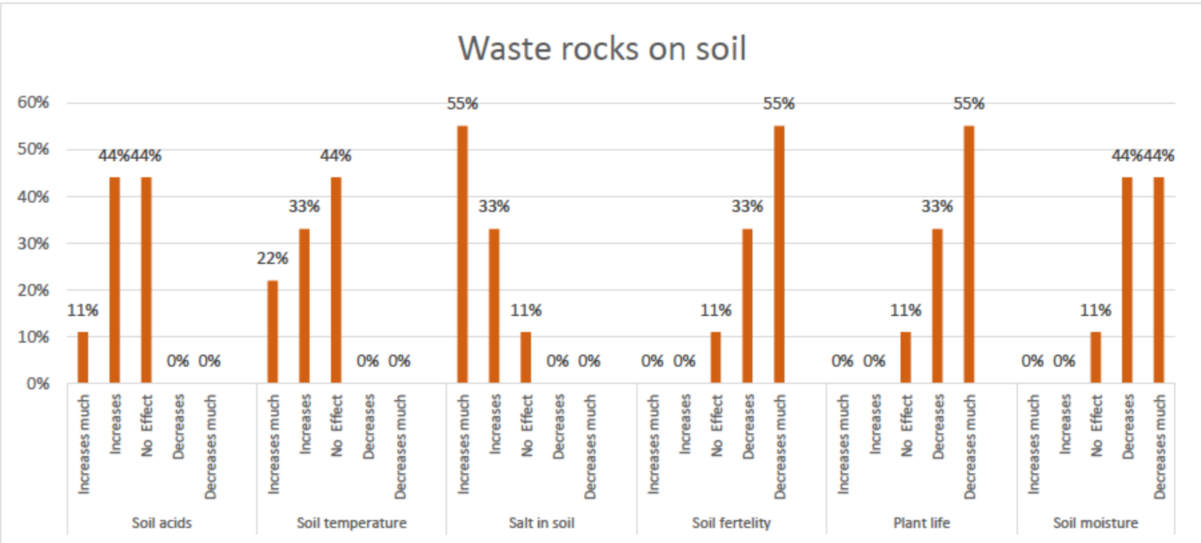

Figure 3.14 ***Waste Rocks on Soil***

Fig.3.14 above demonstrates how waste rocks (rocks thrown out after extracting gold) affect soil around the community, about 55% of the participants said "*soil fertility* "decreases much making it yet difficult to grow crops and 55% said "*salt in soil*" increases much.

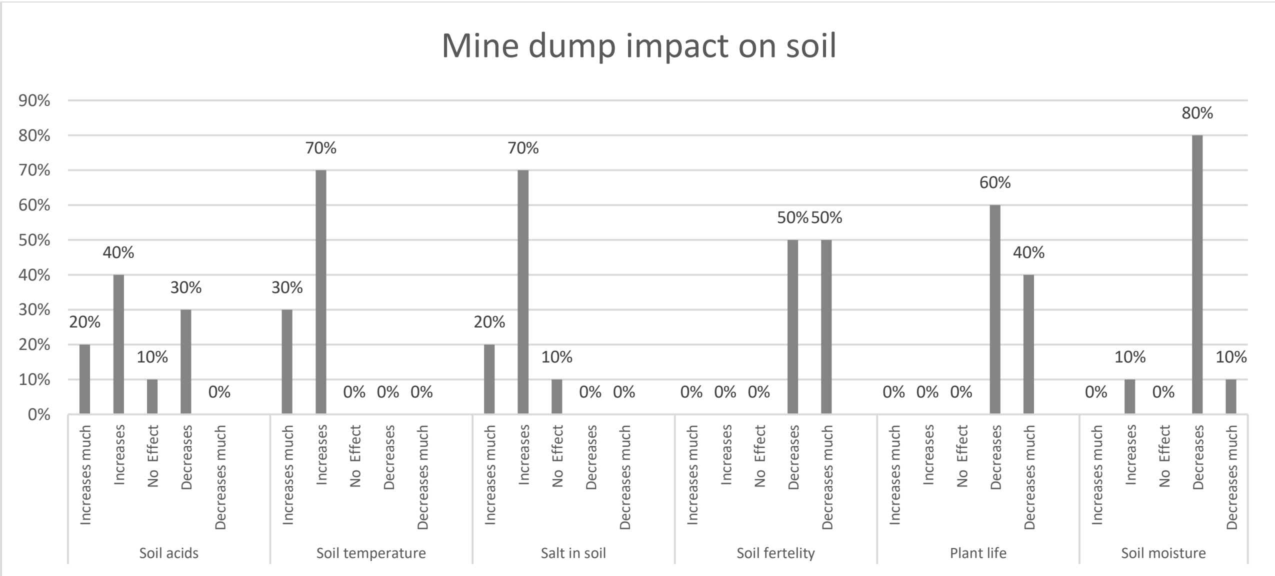

Figure 3.15 ***Mine Dumps Impact on Soil***

Fig.3.15 demonstrates how mine dumps affect soil around the community, about 70% of the participants said "*soil moisture* "decreases much and 40% said "*salt temperature*" increases much.

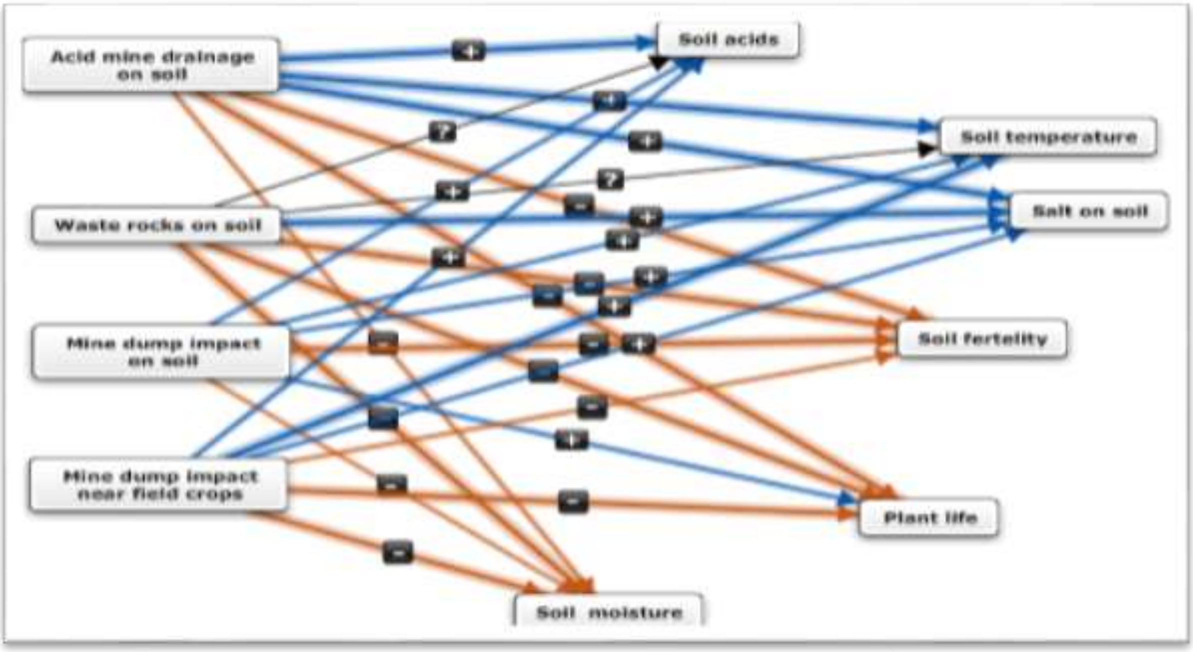

Figure 3.16 ***FCM for Soil Indicators and Causal Effects***

Fig.3.16 indicates the causal effect soil indicators have on each other. Like "*mine dump impact on soil"* decreases "*soil fertility"*.

	Acid mine drainage on soil	Soil acids	Soil temperature	Salt in soil	Soil fertelity	Plant life	Soil moisture	Waste rocks on soil	Mine dump on soil	Mine dump near field crops
Acid mine drainage on soil		1	1	1	-1	-1	-0.5			
Soil acids										
Soil temperature										
Salt in soil										
Soil fertelity										
Plant life										
Soil moisture										
Waste rocks on soil		0.5	0	1	-1	-1	-1			
Mine dump on soil		0.5	0.5	0.5	-1	-0.5	-0.5			
Mine dump near field crops		0.5	1	0.5	-1	-1	-1			

Figure 3.17 ***FCM Matrix for Soil Indicators and Causal Effects***

Fig.3.17 represents matrix of soil indicators, as elaborated in section 3.6.5 above about how the causal effects work, in this matrix "*acid mine drainage on soil"* increases acid in water much (1) and "*soil fertility*" decreases much (-1).

Impact of mine activities on air

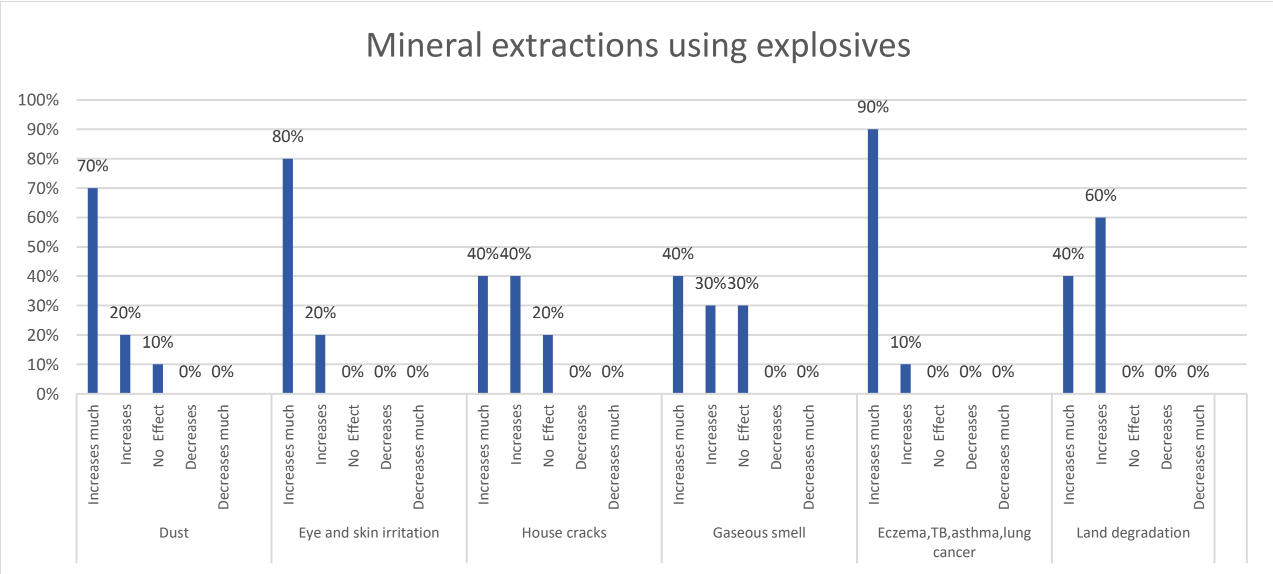

Figure 3.18 ***Extracting Minerals using Explosives***

Fig.3.18 demonstrates how dust that comes from mining when digging for gold (rocks affect air that we breath, 90% of the participants said this dust causes them illnesses like eczema, TB, asthma, and lung cancer, 60% of participants said land degradation increases much, the houses crack as a result of the explosives.

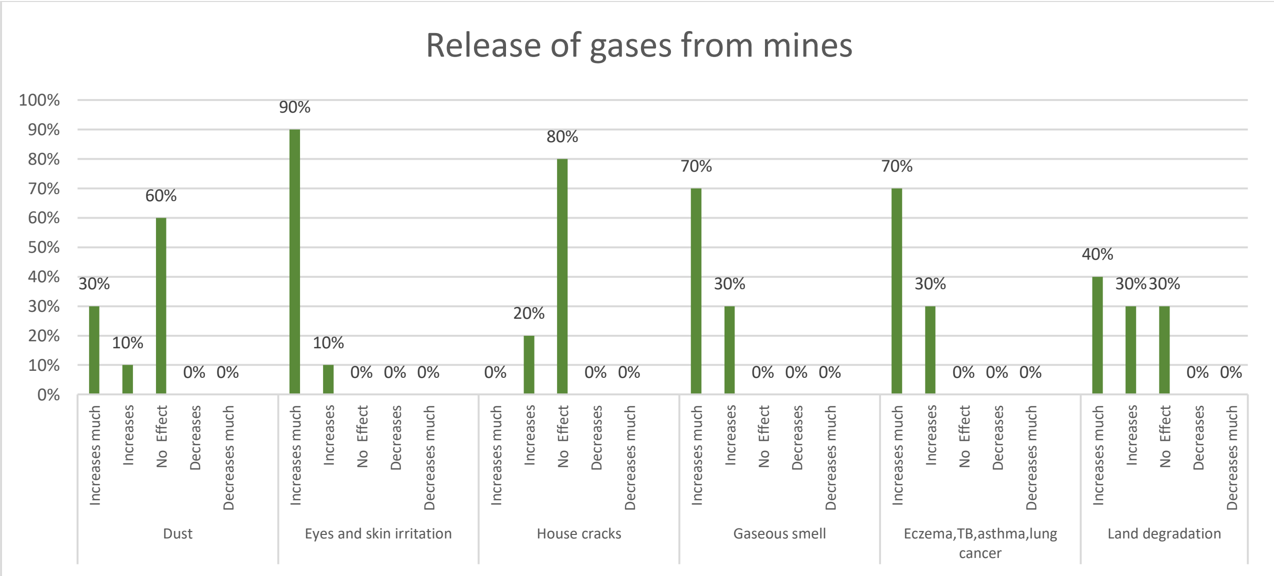

Figure 3.19 ***Release of Gases from Mines***

Fig.3.19 demonstrates how gases such as methane affect the community, around 90% of participants said the gases irritate their eyes and skin, and 70% said the smell of these gases is all around the atmosphere and it affects their wellbeing.

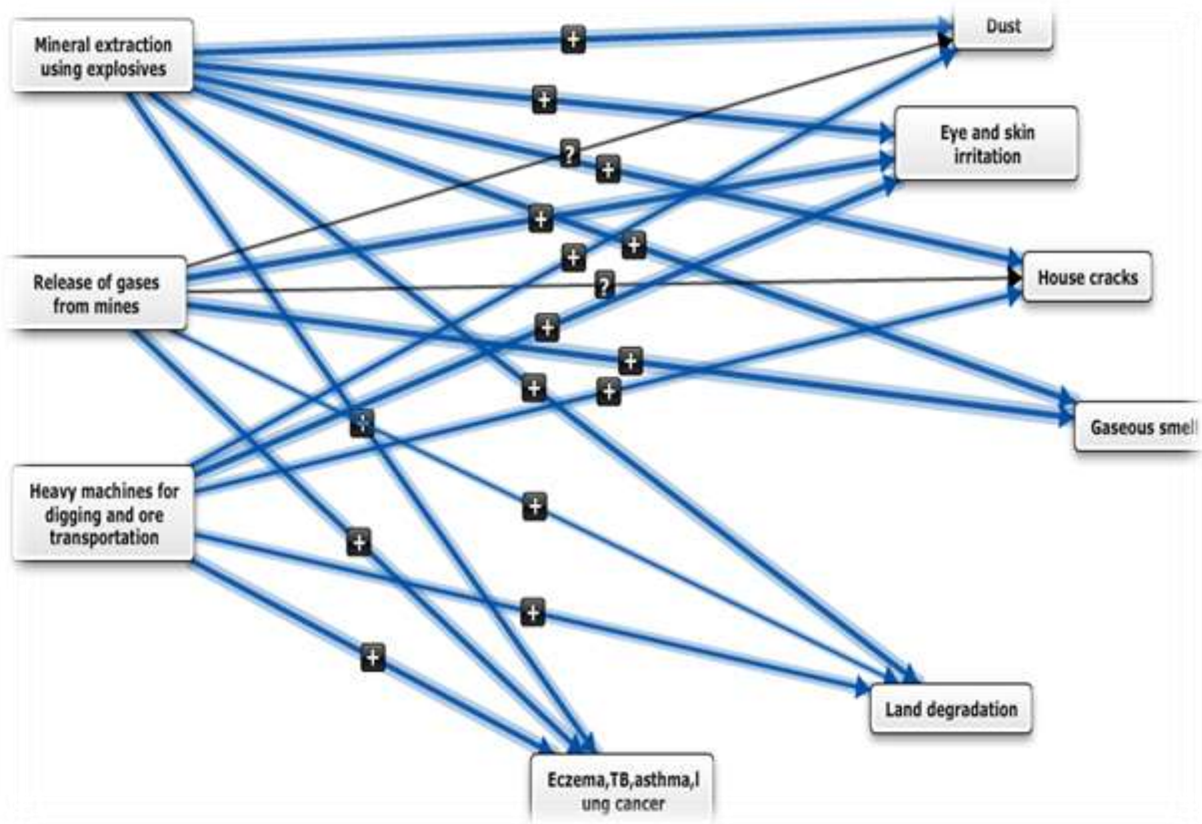

Figure 3.20 ***FCM for Air Indicators and Causal Effects***

Fig.3.20 indicates the causal effect air indicators have on each other, like “*release of gases from mines”* increases “*eyes and skin irritation”* and it has no causal effect on *“dust”.* In this figure *“no causal effect”* is represented by a question mark *“?”*

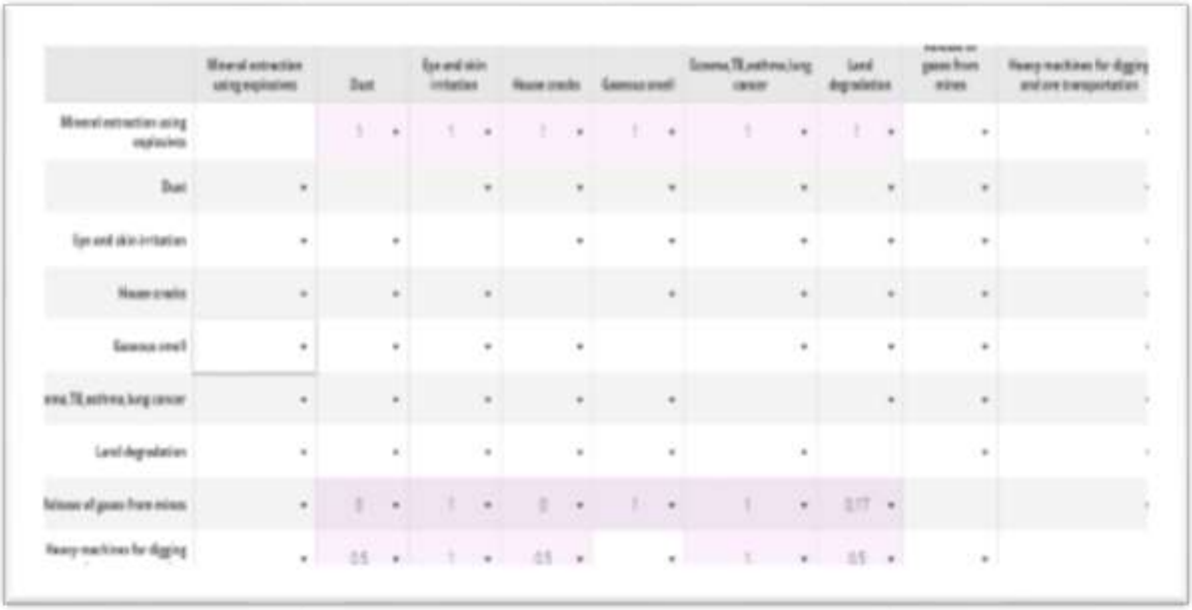

Figure 3.21 ***FCM Matrix for Soil Indicators and Causal Effects***

Fig.3.21 represents matrix of air indicators, as elaborated in section 3.6.5 above about how the causal effects work, in this matrix “*release of gases from mine”* increases “*eye and skin irritation*” in the atmosphere much (1) but has no effect on “*Dust*”.

4. SYSTEM DESIGN AND DEVELOPMENT

4.1 INTRODUCTION

The main goal of this research was to develop an adaptive environmental management system that integrates two useful knowledge's (scientific and local) when it comes to environmental pollution monitoring in the district of Lejweleputswa. In this chapter, the focus is on the architecture of the system; this architecture is the foundation of the system implementation and it consists of three components: (1) capturing and storing pollution knowledge; (2) monitoring pollution; (3) and disseminating and communicating pollution knowledge. The first part of this chapter is a brief description of ICTs tools used in the adaptive environmental management system, followed by a conceptual framework of the system. The second part of the chapter is about the architecture; an overview of the first component is explained. This is about using wireless sensor networks, and mobile phone to capture pollution data. Then second component that monitors pollution is explained. We then show how monitored data will be disseminated to the registered users and how users can send in extreme event related to pollution. Lastly, we explain the design and implementation of the system.

4.2 THE ICTs AND LOCAL KNOWLEDGE INVOLVED IN THE ASSEMBLY OF THE SYSTEM

Figure 4.1 *Components of an Adaptive Environmental Management System*

4.2.1 Wireless Sensor Network

When it comes to monitoring environmental data in South Africa, conventional pollution monitoring stations are used to continuously measure the most important pollutants and report to pollution monitoring systems. To install new conventional monitoring stations is too expensive for each community. The first part of our architecture uses cost-effective wireless sensor network that act as monitoring station, these sensors can be deployed anywhere in the community to provide accurate and relevant monitored data to the local community.

4.2.2 Local Knowledge

Local communities depend or trust information that they learn for themselves, information that is within them and 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 prevent environmental pollution around them. This knowledge is collected by an android mobile application for storage and monitoring purposes.

4.2.3 Fuzzy Cognitive Maps

To make sure that all the data collected from the community is monitored, the system had to make use of artificial intelligent technique called fuzzy cognitive maps(FCMs); FCMs group the indicators from the community and make decisions based on scenarios.

An FCM consists of nodes or concepts, Ci, i = 1…N, where N is the total number of concepts. Each interconnection between two concepts Ci and Cj has a weight, a directed edge Wij, which is similar to the strength of the causal links between Ci and Cj. Wij from concept Ci to concept Cj measures how much Ci causes Cj. In simple FCMs, directional influences take on trivalent values {-1; 0; +1}, where -1 indicates a negative relationship, 0 no causal relation, and +1 a positive relationship (Papageorgiou & Kontogianni, 2012).

In the example of (Fig.4.2) which is an FCM of local knowledge on environmental pollution, the directed edge Eij from causal concept Ci (in this example, it could be a windy season) to concept Ci (which is particles from mine dumps) measures how much Cj influences Ci meaning during windy seasons, heavy metals particles fall from mine dumps into the community thus contributing to air pollution. The edges Eij take values in the fuzzy causal interval [–1, 0, 1]. Eij= 0 indicates no causality Eij> 0 indicates causal increase, Cj increases as Ci increases (or Ci decreases as Cj decreases. Eij< 0 indicates causal decrease/negative causality. Cj decreases as Ci increases (or Cj increases as Ci decreases). Observing this graphical representation, it becomes clear which concept influences other concepts by showing the interconnections between them. Moreover, FCM allows updating the construction of the graph, such as the adding or deleting of an interconnection or a concept, making it adaptive to change, for example, when seasons change, the concept of Ci (windy season) can be deleted and new one added to see how changes occur. FCMs are used to represent both qualitative (smell, dust) and quantitative (mine dumps) data. The construction of a FCM requires the input of humans' experience and knowledge on the system under consideration and then integrate the accumulated experience and knowledge concerning the underlying causal relationships amongst factors, characteristics, and components that constitute the system.

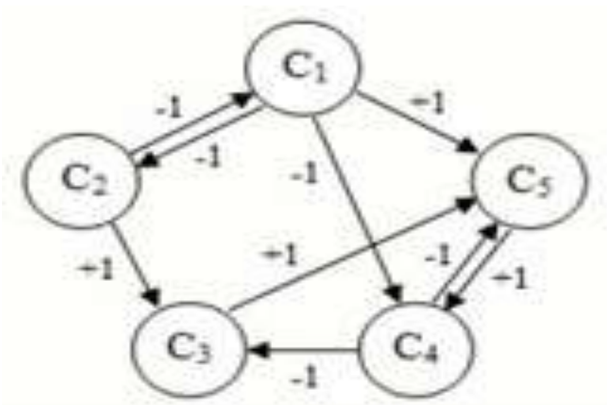

Figure 4.2 ***A simple FCM Representation***

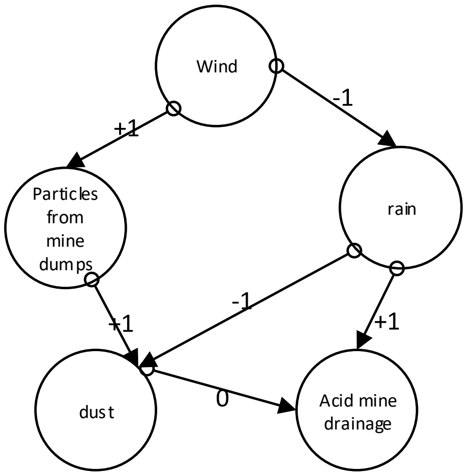

Figure 4.3 ***Example of FCM for Environmental Pollution Indices***

Representation of Concepts in Fuzzy Cognitive Maps

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.

Concepts Description

The following table gives the descriptions of all the 18 concepts {C_1……C_{18}}.

Table 4-1 Description *of Concepts*

Concept Symbol	Concept	Description
C_1	rain	
C_2	white dust	The dust that is formed by particles from mine dumps
C_3	acid mine drainage	Drainage formed by water and heavy metals from mine dumps or abounded shafts
C_4	wind	
C_5	particles from mine dumps	Heavy metals that are leached from mine dumps by wind
C_6	black soil	Soil contaminated by mine waste and got into contact with water
C_7	orange water	Water contaminated by acid mine drainage
C_8	foul smell	Smell caused by contaminated water
C_9	white soil	Soil contaminated by mine waste
C_{10}	gaseous smell	Smell caused by release of gases coming from underground mine
C_{11}	atmospheric moist	Moisture in the air that is caused by gases around
C_{12}	soil fertility	Affected soil fertility that makes it difficult to plant
C_{13}	asthma	Side effects caused by dust and smell
C_{14}	eczema	Side effects caused by dust and smell
C_{15}	eyes irritation	Side effects caused by dust
C_{16}	skin irritation	Side effects caused by dust and particles from mine dumps
C_{17}	Lung cancer	Side effects caused by dust and smell
C_{18}	TB	Side effects caused by dust

Representation of Causal Effects

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 4.2. This matrix is called as weight matrix. The name of all the concepts are written as row heading and concepts symbol like C1, C2, etc. are written as column heading. 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 ecological components within the system.

Table 4-2 ***Causal Effects Representation***

Concepts	**Symbol**	C	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	0	-	1	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0
white dust	C	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0.	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	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
particles from mine	C_5	0	1	0	0	0	0	0	0	0.25	0	0	0	0	0	0	0	0	0
black soil	C	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0
orange water	C_7	0	0	0	0	0	0	0.	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	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0
gaseous smell	C	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
asthma	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
eczema	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
eyes	C	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	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TB	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fuzzy Cognitive Map Chart

The model of fuzzy cognitive map is used to express various concepts and the relationship between these concepts. Eighteen concepts are used in this model; these are the factors which are used to identify relationship between different environmental pollution indicators as decided by experts. Weighted arcs describe the relationship between concepts. Graphical representation of the above along with their degree or weight age is shown in Fig.4.4.

From the 18 concepts represented in Table 4.2 the matching relationships were graphically represented as shown in Fig.4.4 These relationships describe the impact of one concept on other concept. If the relationship is directly proportional, then positive value on the arc is written. Directly proportional means that concept is directly effecting 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 on the other. For example, if it is 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.

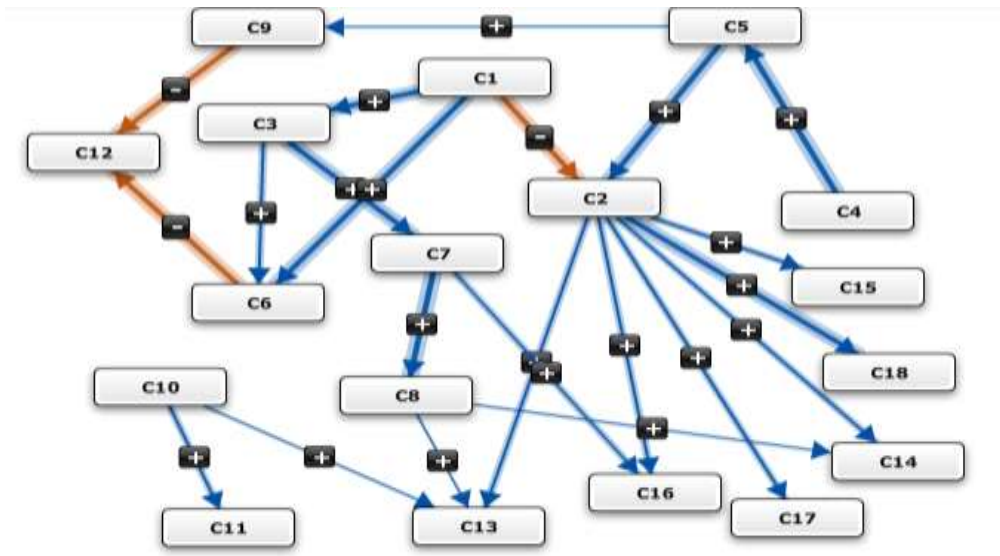

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Figure 4.4 ***Relationship Between Concepts***

Scenarios

Scenarios were undertaken to determine how the system might react to plausible changes to health or environmental components within the system. The Scenario interface of Mental Modeller allows the dynamic effects of alternate management intervention scenarios, given the current level of group understanding of the system, to be evaluated. For instance, as a result of building a shared community model of the environmental monitoring system, stakeholders in Matjhabeng municipality developed a hypothesis that rehabilitating mine dumps might alleviate some air, soil and water pollution. In terms of dust and acid mine drainage, the Fig.4.5 below shows a scenario where no indicator was added or deleted.

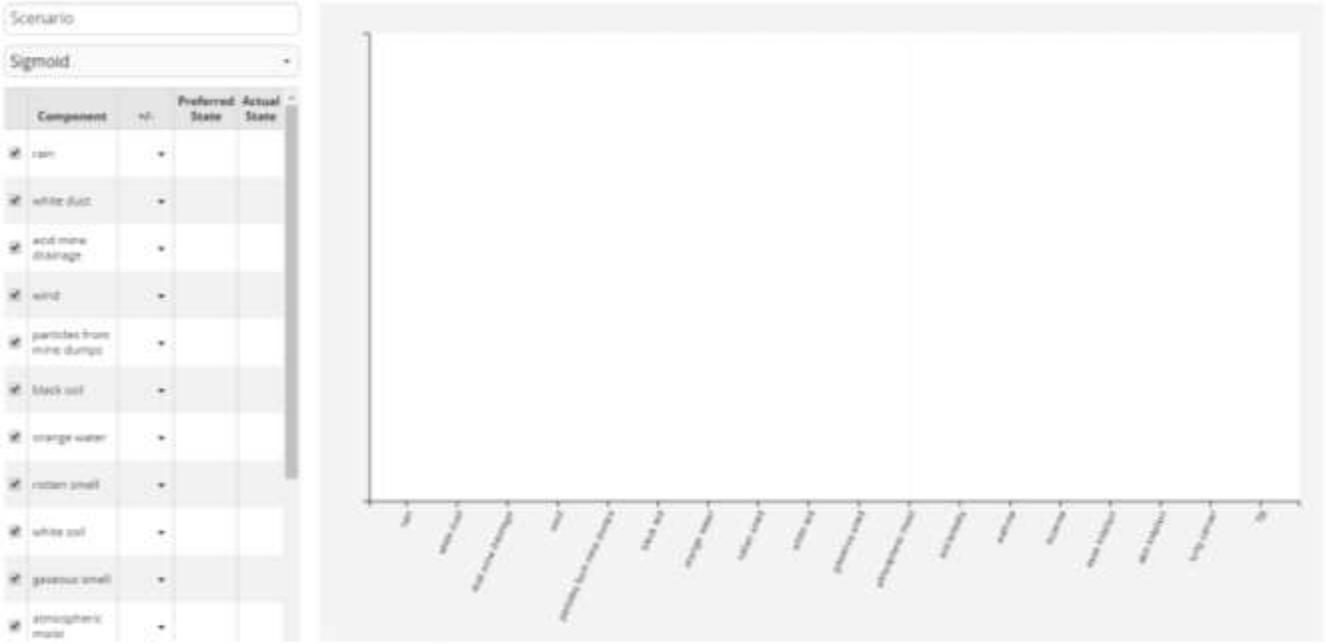


Figure 4.5 ***Scenario with no Changes Made to the Concepts***

Fig.4.5 also shows no changes made to the system. Several scenarios could be proposed and run in real time to recognize the adaptation of the environmental monitoring system and what could be done to reduce the level of impact pollution has in the community.

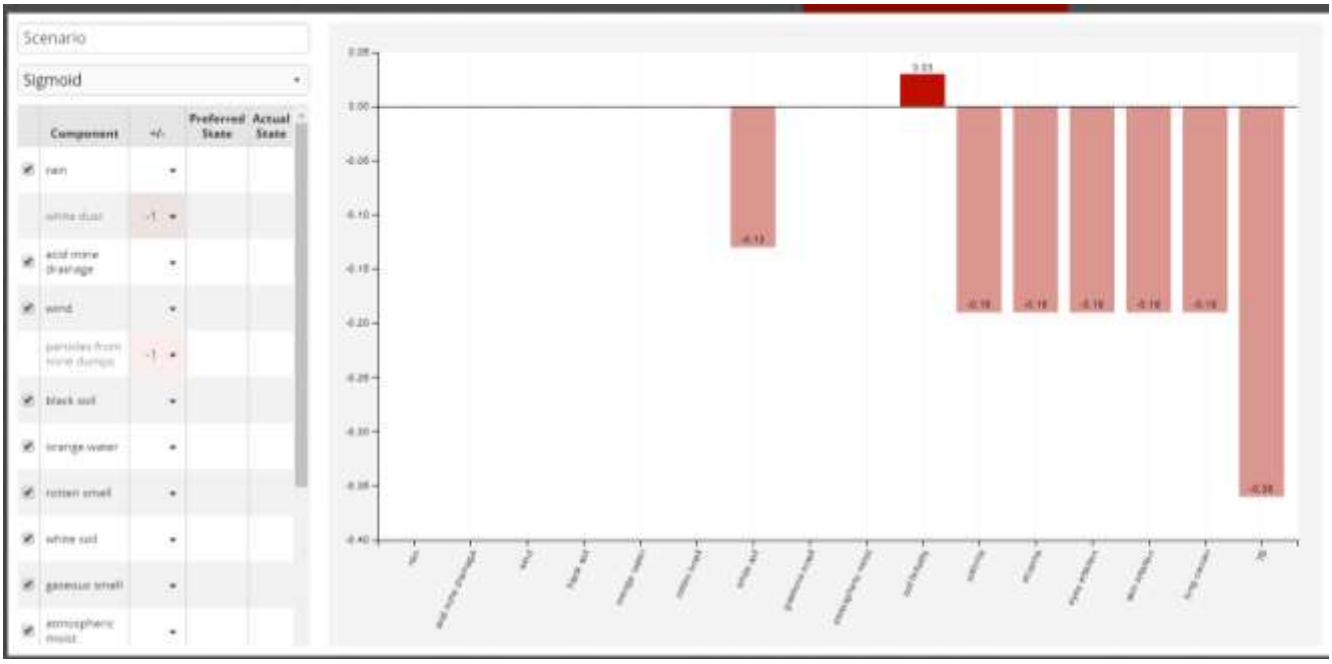


Figure 4.6 ***Hypothetical Scenario Output of Reducing White Dust and particles from mine dumps***

Running with the scenario of decreasing “particles from mine dumps and release of heavy metals from mine dumps” scenario provided confirmation of reduction in dust as well as acid mine drainage and increase in soil fertility (Fig.4.6 above).

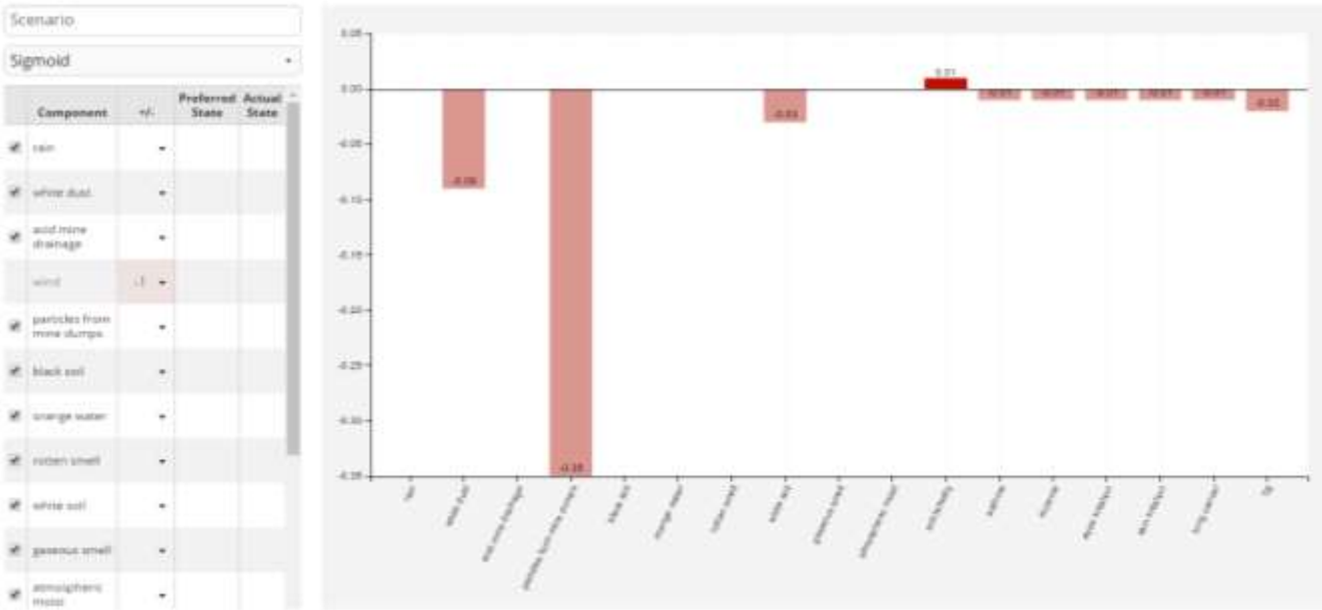


Figure 4.7 ***Hypothetical Scenario Output of Season Change (where there is no wind affecting mine dumps)***

Another scenario was where change of season took place (Fig.4.7 above) resulting in no wind affecting mine dumps. This scenario confirms that no particles will be released from mine dumps resulting in less white dust, less health issues such as eye irritation and TB.

Based on the outcomes of these scenarios, hypothesized environmental monitoring system was developed. The Scenario interface of Mental Modeler allows the dynamic effects of alternate management intervention scenarios, given the current level of group understanding of the system.

4.3 ADAPTIVE ENVIRONMENTAL MANAGEMENT SYSTEM ARCHITECTURE EXTENDED

The framework is composed of three elements (data capturing, monitoring and dissemination) that work together to produce an integrated system. The design is based on the generic early warning system framework developed by the United Nations Office for Disaster Risk Reduction (UNISDR) (ISDR, 2006).

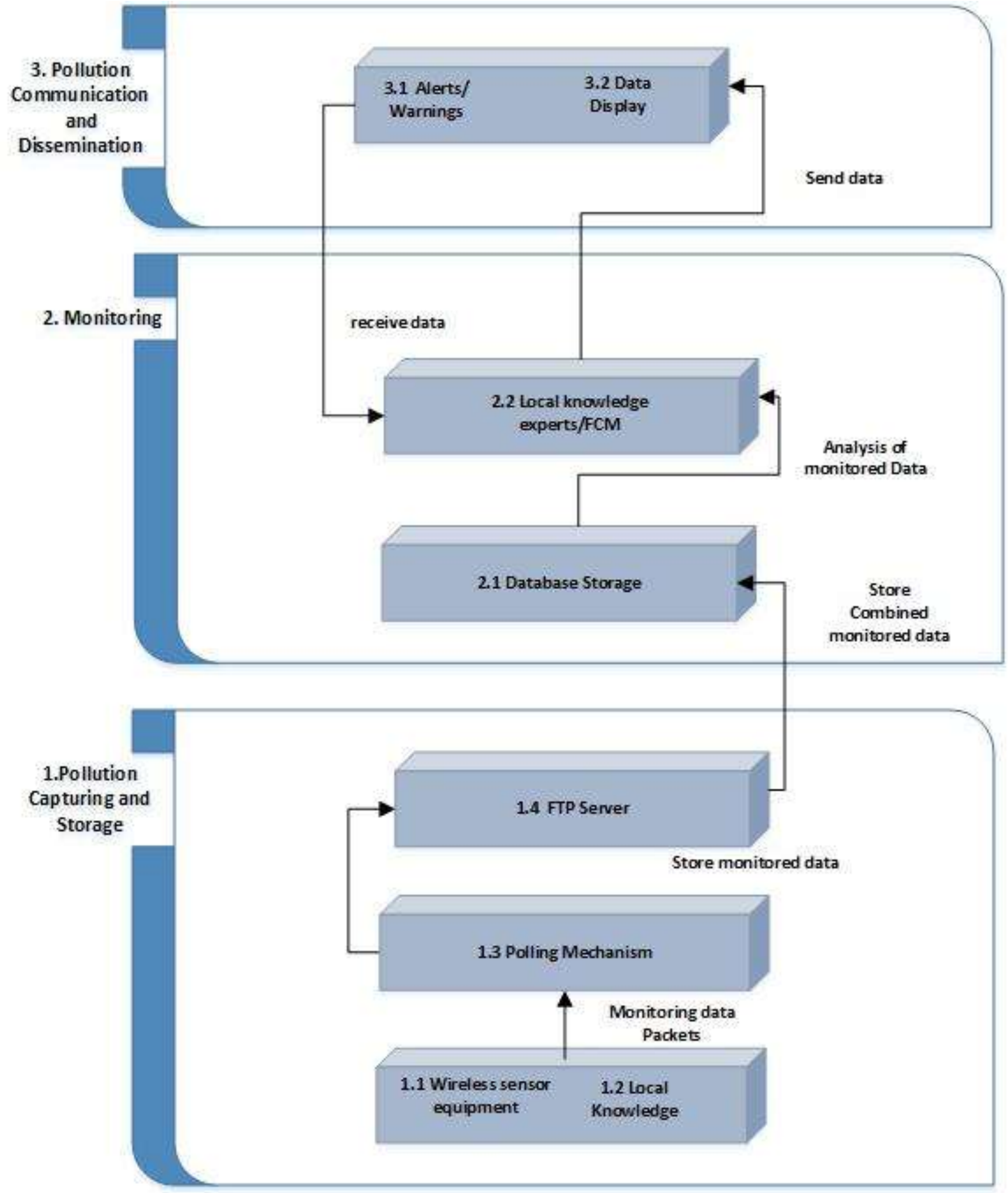


Figure 4.8 Adaptive *Environmental Management System Architecture Extended*

4.3.1 Pollution Knowledge Capture and Storage

Source 1: Wireless Sensor Networks

In 1.1 Environmental pollutants such as carbon dioxide and methane are collected by wireless sensor equipment; Libelium Waspmote gas sensor board.

1.3 A GPRS module (polling mechanism) that comes with Libelium wireless sensor equipment acts as a bridge between hardware and software to obtain sensor data. The main function designed for this was to use a timer to send out a query command to a unique sensor when the timer triggers. Sensors send back monitoring data when they receive the query command and sends data by SMS to the FTP server (1.4). In this study, the timer is set to 30 minutes.

1.4 The FTP server stores pollution data from wireless sensors temporarily, then send the data to the MySQL database for storage.

Figure 4.9 ***Libelium Waspmote Gas Sensor Board***

Figure 4.10 ***Libelium Waspmote GPRS Module***

Source 2: Local Knowledge

For 1.2 an intermediary person sits with the experts of local knowledge to collect the knowledge, after the experts reach an agreement on the indicators of pollution, the intermediary translate the information and keys it into the system for storage, monitoring and visualization purposes in the knowledge database using an android mobile application.

Extreme events are sent to the intermediary person via SMS by the users, the intermediary person validates the number by checking if it is stored in the database. The intermediary person will then forward extreme events to all registered users. Extreme events are any irregularities that happen to local knowledge indictors, such as having heavy metals flow into the atmosphere even if it is not a windy season; mine pipes bursting and the drainage making way into the water streams. If extreme events sent by the user are falsified, the user is blocked from sending anymore events.

4.3.2 Pollution Monitoring and Visualisation

This component consists of two sub components namely pollution monitoring and pollution prediction;

Pollution Monitoring

2.1 Sensor data that is received by the FTP server is sent to MySQL database after every 30 minutes for monitoring and then compared to the already provided quality standards.
2.2 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.

4.3.3 Pollution Knowledge Dissemination

The system provides three methods for dissemination based on user preference;

Android mobile application

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.

SMS Ability

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.

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.

4.4 SYSTEM ANALYSIS AND DESIGN

This section focuses on understanding the requirements of the system and how it operates, also this is illustrated using use case diagrams, sequence diagrams, and the entity relationship diagram to show different classes of the system and how the relate to one another.

4.4.1 System Development Approach

Given the nature of adaptive systems, a more adaptive development approach, (Agile in this case) was used. The traditional software development models are not flexible to changes in requirements resulting in software development and deployment delays. Furthermore, software's become over budget because any changes in the requirements at the later stage of software development is very expensive using traditional software models (Ullah, 2014).This approach assumes that various phases of the project can be completed sequentially, it is almost not used anymore (Satzinger, et al., 2011). In comparison to traditional software processes, agile development is less document-centric and more code-oriented. This, however, is not the key point but rather a symptom of two deeper differences between both (Paetsch , et al., 2003).

The Agile method the researcher used is called extreme programming(XP), XP is a discipline of software development based on values of simplicity, communication, feedback, and courage, It works by bringing the whole team (including clients) together in the presence of simple practices, with enough feedback to enable the team to see where they are (Choudhari, 2015). As a type of agile software development, it advocates frequent “releases” in short development cycles, which is intended to improve productivity and introduce checkpoints where new customer requirements can be adopted. This method helped the researcher to develop the adaptive system with the help of the users. The researcher developed the system in releases that were continuously checked for errors then integrated into one functioning system. The users were the critical part of the development, as their input was the integral part of the system from gathering requirements and creating the FCM to development and testing of the system. The users saw the system grow from layer upon layer of detail. The software is only as effective as the details it embodies.

4.4.2 Specification Requirements

As part of planning phase for the system, the researcher had to identify the tools needed to accomplish the task of developing this system: below are the functional, non-functional requirements hardware and software requirements the systems needs in order to operate:

Functional requirements

The system consists of three sub –systems: the SMS, mobile application and a web portal.

1. The registered users and decision makers can request 1-day information for environmental pollution from the system.
2. The registered users can send into the system the observed monitored conditions based on their local knowledge regarding pollution (air, soil, water). This functionality only exists on the mobile application
3. The registered users can send into the system extreme pollution events related to already provided pollution indicators. This functionality is excluded on the web portal.
4. The public users and decision makers can view articles, reports or any related information about pollution. This functionality exists on the web portal only.
5. The users can view the locations of pollution graphically. This exists only on the mobile application and web portal.
6. The system can send out alerts to the registered users once the level of pollution is considered harmful. This exists for SMS Application only.

No-Functional requirements

These are the requirements, which are not the functionalities of a system but are the characteristics of a system

1. The system is mobile, making it available 24/7.
2. The system is descriptive in in terms of dissemination purposes.
3. The system is adaptable making it highly desirable for future extensions.

Table 4-3 ***Hardware and Software Requirements***

Hardware Requirements	**Software Requirements**
1. Libelium Waspmote Sensor Board	1. MySQL Database Server
2. Subscriber Identity Mobile(SIM) card	2. Visual Studio 2015 IDE
3. Libelium Gas Sensor Board	3. Android Studio 2.2 IDE
4. GPS sensor	4. Ozeki SMS Gateway
5. GPRS sensor	5. Wapmote IDE
6. Dongle	6 NetBeans 8.1 IDE
7. Secure Digital(SD)Card	

4.4.3 System Use Case

After identification of the system's requirements as summarized above the researcher used the requirements to draw out an overall prototype of the system. This phase of planning and analysis, the functional requirements were used to create an overall use case on how different actors interact with the proposed system.

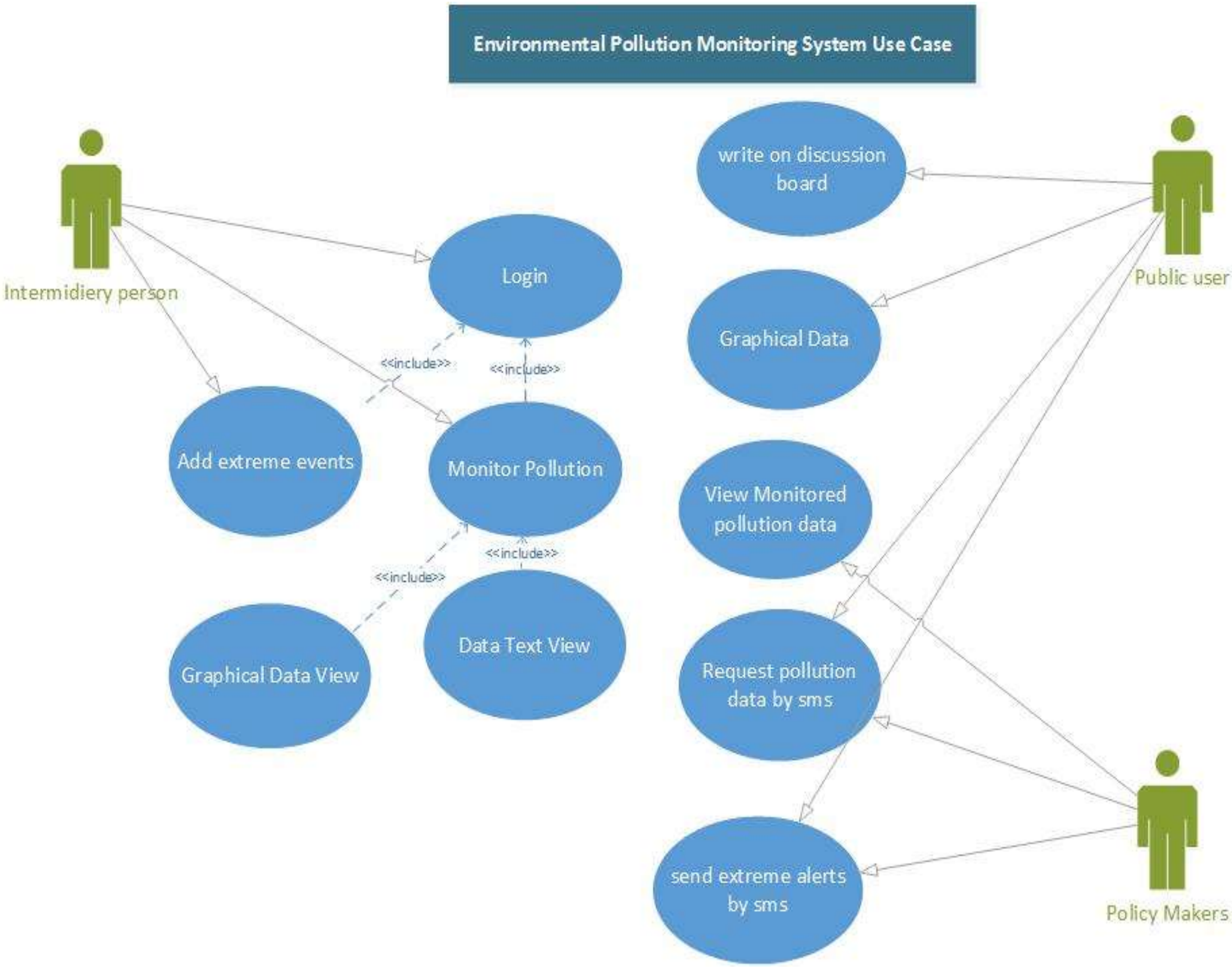


Figure 4.11 ***Overall System Use Case***

The Intermediary person is able to login in into the system by using his/her provided credentials to ensure that he/she is the only one able to add or update local knowledge from the experts of the system.

The decision makers are people who are contributing to the pollution around the community or the municipality; they are also able to request pollution data.

Initial Step-By-Step Description

1.**Login**: The Intermediary person is able to login in into the system by their provided credentials to ensure that they are the only one's able to operate on the mobile application system.

2. **Extreme events**: once the intermediary person has logged into the system, they are able to report on currently observed extreme events related to the indicators. They specify if the event is acceptable, harmful or just moderate for the community. This information is stored in the database and sent to registered users via SMS.

3. **Monitor pollution**: the intermediary person is also able to monitor the changes happening to the indicators; once they observe the changes they key them into the system and saved inside the database.

4. **View text data**: monitored indicators, effects, extreme events, report from CO2 and CH4 sensors as well as their location is displayed for the intermediary person to see report of each day.

5. **View graphical data**: The system provides the intermediary person with the option of graphical view to see the location of gas pollutants (which is stored in the database from the GPS sensor) and their current level using Google Maps.

6. **Discussion board**: on the web portal sub-system, the public users and policyholders are able to write on the discussion board to discuss their views regarding pollution around the community.

7. **Graphical data**: the web portal subsystem allows the public user as well as the policyholder to view the location of the gas pollutants using Google Maps.

8. **Monitored data**: the public users as well as policy makers are able to view extreme pollution events, observed monitored indicators as well as level of gas pollution around the community.

9 **Pollution data request**: public users are allowed to request 1-day pollution information (extreme events, monitored indicators, C02 and CH4 levels) only if their cell phone numbers are registered with the system.

10. **Extreme event alerts**: public users are able to send in extreme events via SMS to the intermediary person for report, and then the intermediary person sends the events to the registered users.

4.4.4 Database Design

A database is a collection of information that is organized and stored on a computer, this information is also called “data,” which is why a collection is called a database (La Bella, 2014). From the system requirements gathered, the following relational database and tables on Fig.4.12 was decided upon by the researcher to meet the requirements of the adaptive environmental management system prototype. It is the initial raw database design and the relationships among different entities that help in storage, retrieval, updating of system activities.

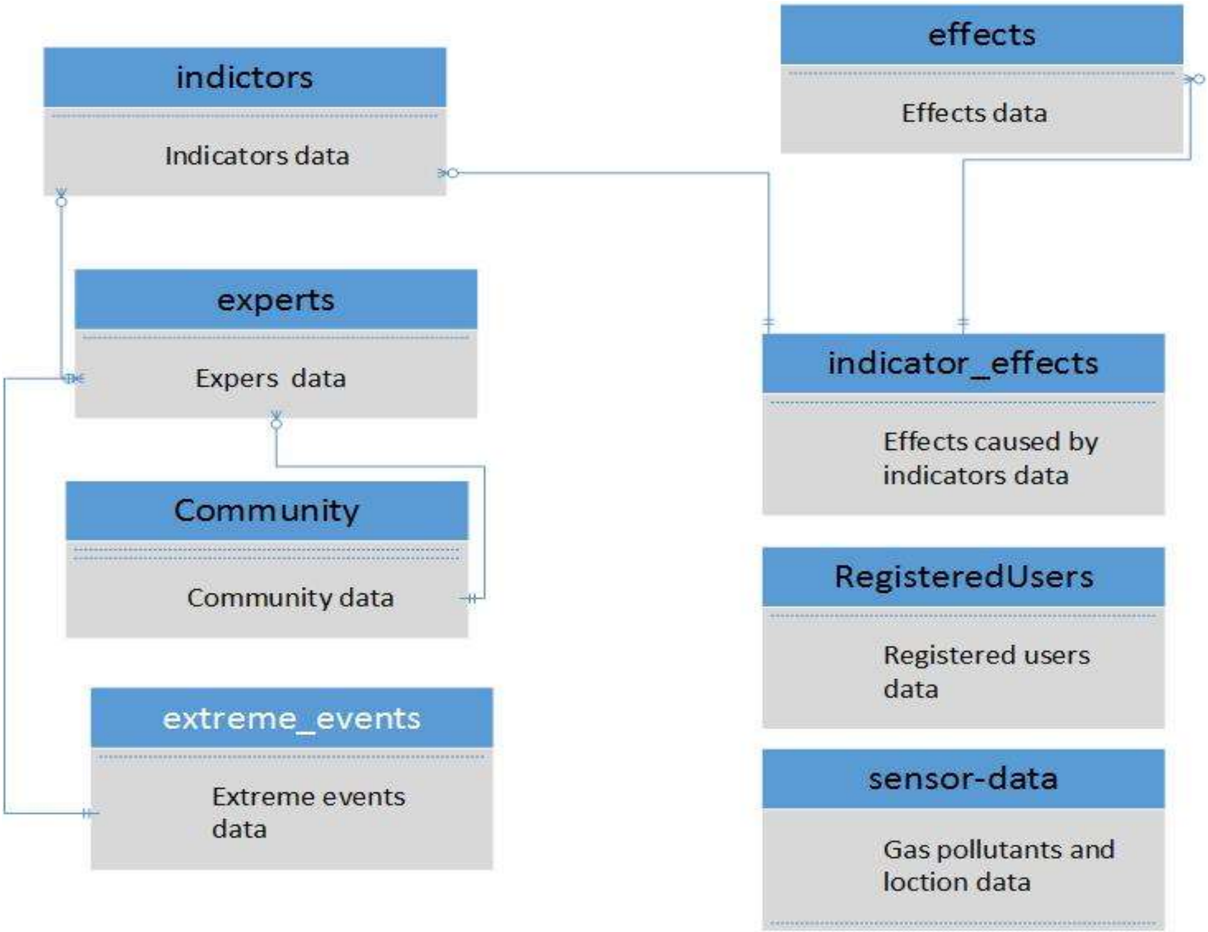


Figure 4.12 ***Initial database entity identification***

4.5 System Implementation

The development approach decided upon by the researcher assisted this project when implementing the system in sets by making use of Use cases, Entity relational Diagram and sequence diagrams. This helped in constructing the system in a well-balanced and effective manner, it omitted adjacencies and critical errors. After completion of each system release, the researcher would allow the focus group to test the release in order to receive any new input or route. This allowed the researcher to always be in line with the user's needs.

4.5.1 Database Implementation

The database design for this system was created in MYSQL database, the necessary integrity constraints were implemented as required and in cases where the entity relationship was too compound (as in the case of LK Indicators), stored queries and database triggers were used to envisage the data. The database was normalized for reasons such as:

1. Data integrity (because there is no redundant, neglected data),
2. Optimized queries (because normalized tables produce rapid, efficient joins),
3. Faster index creation and sorting (because the tables have fewer columns),
4. Faster UPDATE performance (because there are fewer indexes per table),
5. Improved concurrency resolution (because table locks will affect less data) (Microsoft, 2017).

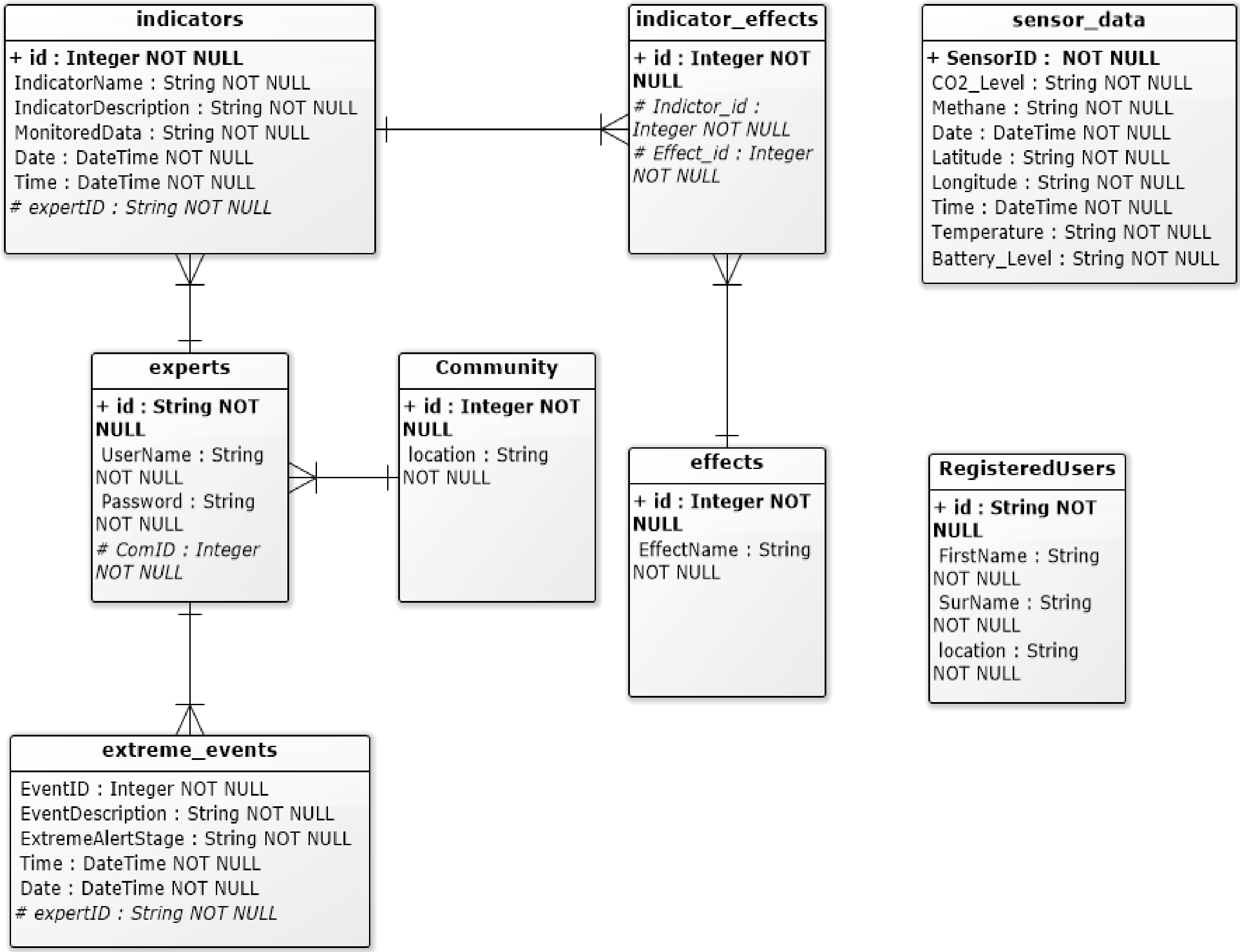


Figure 4.13 ***Overall Database Design***

Data from fuzzy cognitive maps that was discussed in section 4.2.3 is pre-stored in the database. The concepts from table 4.2 were converted into indicators and effects based on how they influenced one another, this is represented by tables “indicators” and “*indicator _effects*” in the database.

4.5.2 Waspmote Programming

```
}
void getCO2()
{
  co2Val = SensorGasv20.readValue(SENS_CO2);
  float y= 0.2 - co2Val; //Voltage(at 350 ppm) is 0.2V
  //converting voltage reading to ppm
  CO_2_In_PPM = pow(10,(co2Val + 158.631)/62.877 );
  USB.print(F("Carbon Dioxide: "));
  USB.print(CO_2_In_PPM);//print value in PPM
  USB.println(F("  PPM"));
  Utils.float2String(CO_2_In_PPM ,CO_2_In_PPM_String,10);//convert to string
}

void GetLPG()
{ // Read the sensor
  socket2AVal = SensorGasv20.readValue(SENS_SOCKET2A);
  // Conversion from voltage into kiloohms
  socket2AVal = SensorGasv20.calculateResistance(SENS_SOCKET2A, socket2AVal, GAIN2, RESISTOR);
  USB.print(socket2AVal);
  USB.println("kohms");
   // Conversion from sensor resistance in kiloohms in parts per million
  LPG_In_PPM = SensorGasv20.calculateConcentration(coCalibrationConcentration,coCalibrationOutput,socket2AVal);
   USB.print(F("Methane: "));
  Utils.float2String(LPG_In_PPM ,LPG_In_PPM_String,10);//convert to string
  USB.print(LPG_In_PPM);
  USB.println(F("  PPM"));
}
```

Figure 4.14 ***Waspmote Gas Sensors Programming***

Fig.4.14 above shows how carbon dioxide and methane were monitored, here the C++ code is used to accomplish the following: read the CO2 and CH4 levels from the sensors placed at Nyakallong near target Mine, the levels are converted from voltage (which is read by the sensors) to parts per million (ppm) that is compatible to the Gas standards use for comparison when determining if the community is in danger or not. The levels are received by the system and disseminated to the registered users via SMS, they are sent as alerts if they exceed the standards mentioned in chapter 2 section 2.2.4.

```
void loop()
{
  creteFile();
  //  Getting Temperature
  GetTemp();
  //Getting power level
  GetBatteryL();
  //carbon dioxide
  getCO2();
  //GPS
  GetLPG();
  getGPS_Coodinates();
  //SD card
  AppendToSD();
  //gprs and ftp
  GPRSandFTP();
  GPRS_Pro.OFF();
  USB.OFF();
  RTC.OFF();
  GPS.OFF();
  SD.OFF();
  USB.println(F("Sleeping..."));
  //sleeps 30 mins
  PWR.deepSleep("00:00:30:00", RTC_OFFSET, RTC_ALM1_MODE1, ALL_OFF);
  USB.println(F("waking..."));
  USB.ON();
  RTC.ON();
  GPS.ON();
  SD.ON();
  deleteFile();

}
```

Figure 4.15 ***Waspmote Time Intervals***

Fig.4.15 above shows a loop of how the sensor board sleeps and wakes up after 30 minutes, every time the board wakes up the data read by sensors is appended to a text file stored to an SD card, data from text file is then transferred to an FTP Server.

4.5.3 Capturing Observed Indicators

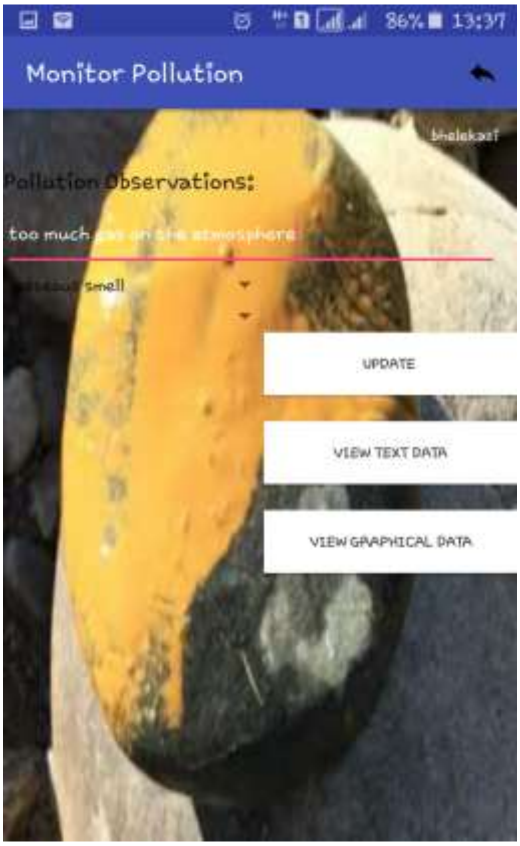


Figure 4.16 ***Indicator Information***

The process involved in Fig.4.16 was shown by the use case in section 4.5.3; Fig.4.11, an outline of that process is explained here; an interface for monitoring(observing) changes occurring on each indicator is presented in above, it displays information required in order to monitor indicators. An indicator being observed must be selected then the description of indicator observations must be keyed in. all the indicators were finalised by FCMs mental modeler software then moved to the database for storage Once the observation has been keyed in and the indictor selected the user clicks on the "Update" button, the systems validates the supplied information. Validation includes checking if the is an indicator selected and that no field is left empty, if any of these is true an error message is elevated and lets the user know that he/she should provide information on the empty field and select an indicator. Once all the relevant data is correct, the system saves the data on MySQL server if there is internet access, if not then data is saved on the SQLite database.

4.5.4 Data Monitoring

```
@Override
    public void run() {
      String printrow = null;
      String queryCO2 = "Select * from sensor_data WHERE CO2_Level >350";
      String queryMethane = "Select * from sensor_data WHERE Methane >1000";
String queryIndicator = "Select * from indicators WHERE Date = '" + getDates() + "'";
      try {
        final Statement stmt = (Statement) connection().createStatement();
        final Statement stmt1 = (Statement) connection().createStatement();
        final Statement stmt2 = (Statement) connection().createStatement();
        final Statement stmt3 = (Statement) connection().createStatement();
        Statement stmt4 = (Statement) connection().createStatement();
        final ResultSet ResultsCO2 = stmt.executeQuery(queryCO2);
        ResultSet ResultsMethane = stmt1.executeQuery(queryMethane);
        ResultSet ResultIndicator = stmt2.executeQuery(queryIndicator);
        ResultSet ResultExtreme = stmt3.executeQuery(queryExtreme);

        boolean RecordsCO2 = ResultsCO2.next();
        boolean RecordMethane = ResultsMethane.next();
        boolean RecordIndicator = ResultIndicator.next();
        boolean RecordExtreme = ResultExtreme.next();
        if (! RecordsCO2 || !RecordMethane || !RecordIndicator ) {
          System.out.println("curremt levels of CO2 AND CH4 are normal ");
   } else {
          do {
            try {
              String CO2 = ResultsCO2.getString(2);
              String Indicator = ResultIndicator.getString(2);
              String Methane = ResultsMethane.getString(3);
              String Indicators = ResultIndicator.getString(4);
              String ExLevel = ResultExtreme.getString(2);
              String ExDes = ResultExtreme.getString(3);
              String selectQueryEffect = "SELECT * FROM  indicators, effects,indicator_effects  WHERE
indicators.IndicatorName = '" + Indicator + "' AND effects.id = indicator_effects.id  AND indicators.id =
indicator_effects.id";
```

```
final ResultSet ResultsindEffect = stmt4.executeQuery(selectQueryEffect);
            if(!ResultsindEffect.next())
            {
            printrow = " Monitored Indicator: " + " " + Indicator + ":\n " + Indicators + "\nExtreme Sensor info: " + "
Carborn dioxide " + CO2 + ":\n Methane " + Methane + "\nExtreme Local info: " + " Extreme Observations " + ExDes + ":\n
Level " + ExLevel;
            System.out.println(printrow);
            for (int x = 0; x < GetPhonenumber("RegisteredUsers").size(); x++) {
                sendMessage(GetPhonenumber("RegisteredUsers").get(x).toString(), printrow);
            }
            }
          else
            {String Effect= ResultsindEffect.getString(1);
            printrow = " Monitored Indicator: " + " " + Indicator + ": \n " + Indicators +"\nEffect: " + Effect + "\nExtreme
Sensor info: " + " Carborn dioxide " + CO2 + ": \n Methane " + Methane + "\nExtreme Local info: " + " Extreme Observations
" + ExDes + ":\n Level " + ExLevel;
            System.out.println(printrow);
            for (int x = 0; x < GetPhonenumber("RegisteredUsers"). size(); x++) {
                sendMessage(GetPhonenumber("RegisteredUsers"). get(x).toString(), printrow);
            }
            }
          } catch (SQLException ex) {
            Logger.getLogger(MyOzSmsClient.class.getName()).log(Level.SEVERE, null, ex);
          } catch (UnsupportedEncodingException ex) {
            Logger.getLogger(MyOzSmsClient.class.getName()).log(Level.SEVERE, null, ex);
          }
        } while (ResultsCO2.next() && ResultsMethane.next() & ResultIndicator.next() && ResultExtreme.next());
      }
      stmt.close();stmt1.close();          stmt2.close();          stmt3.close();          stmt4.close();
    } catch (SQLException ex) {
      Logger.getLogger(MyOzSmsClient.class.getName()).log(Level.SEVERE, null, ex);
    } catch (ClassNotFoundException ex) {
      Logger.getLogger(MyOzSmsClient.class.getName()).log(Level.SEVERE, null, ex);
    }
```

Figure 4.17 ***Monitoring of Sensor Data and Indicators Code***

Fig.4.17 above shows a java code programmed in NetBeans to monitor gas levels every 30 minutes, the application reads levels from MySQL database as well as monitored indicators and extreme events.

4.5.5 Data Dissemination from Mobile Application

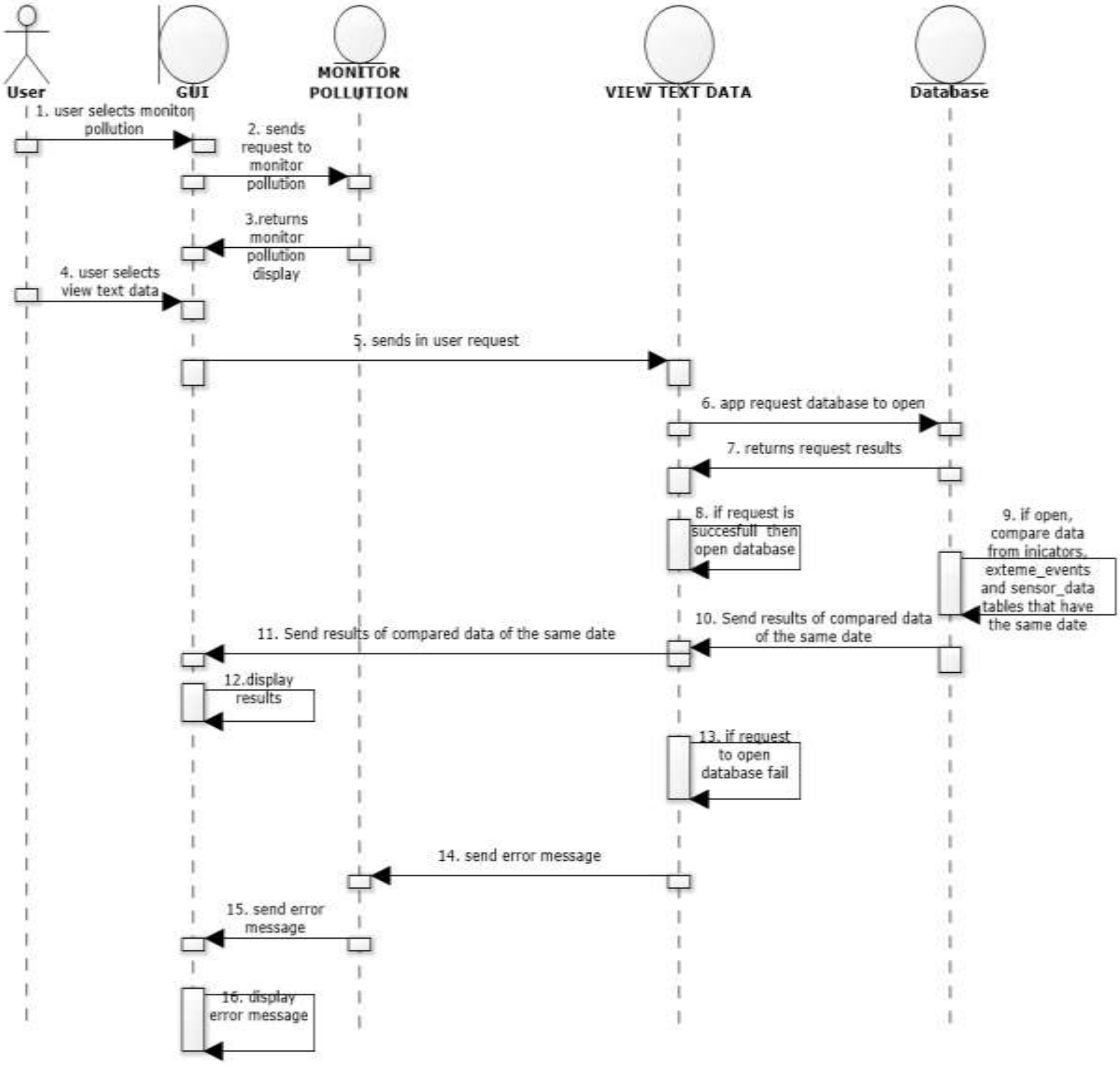


Figure 4.18 ***Displaying Indicators and Sensor Data***

Fig.4.18 displays data observed by the intermediary person pertaining indicators together with associated effects, extreme events and data from sensors that share the same date, the returned results show how monitoring using local knowledge is closely related to monitoring by wireless sensors.

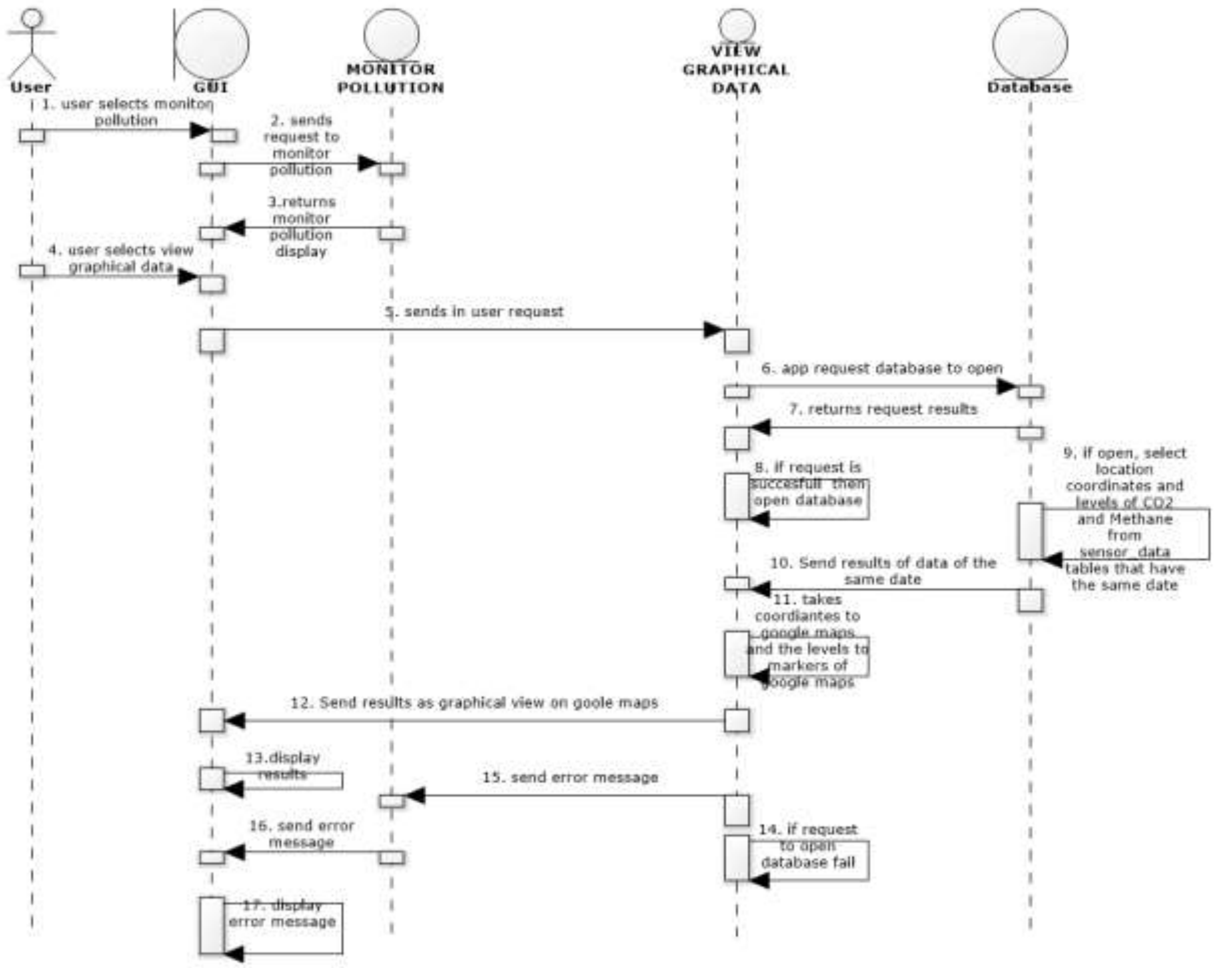


Figure 4.19 ***Graphical View of Sensor Data***

Fig.4.19 outputs graphical representation of monitored pollutants and their location as well as date and time monitoring took place.

Figure 4.20 *View Data Interface*

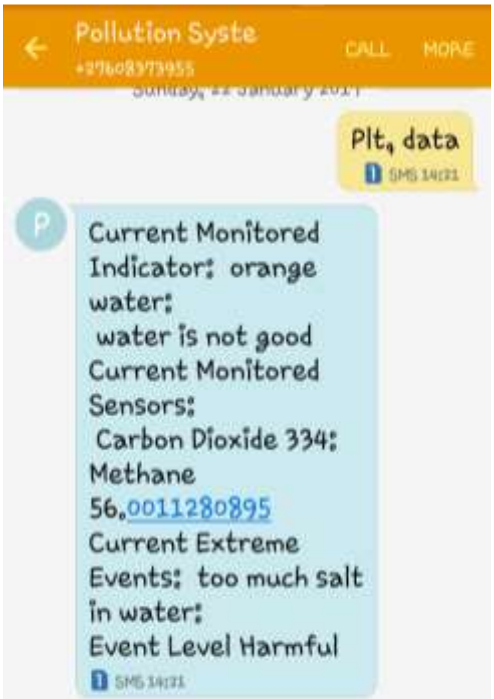
Figure 4.21 *View Graphical Data Interface*

Fig.4.20 displays textual view of monitored indicators as well as local knowledge including effects associated with a specific indicator (if any) and extreme events from a specific day.

Fig.4.21 displays how GPS coordinates gives us graphical view of where sensors are placed as well as the level of the two gases being monitored (CO_2 and CH_4).

4.5.6 Data Dissemination from SMS Application

This component exploits functions of Ozeki SMS Gateway, a Modem and a cell phone that is able to send and receive SMS's. Here the system allows the users to request pollution information for the current date then the system will respond with current sensor, indicator and extreme event information as displayed in Fig.4.22. This figure shows that at 14:21 on 22 January one user requested pollution data from the system by an SMS, what the user does is send an SMS in the following manner: Plt, data where by Plt is for pollution. The Ozeki Gateway will receive the SMS and hand it over to SMS application. The application then decodes the message then perform actions based on the received message to respond. Fig.4.23 below shows an example of how an SMS alert was sent to a user to notify the user about levels of pollution being over the limit, local knowledge observations on indicators and extreme events. The extreme events are sent by registered users via SMS to intermediary person who is able to key them in to the system.



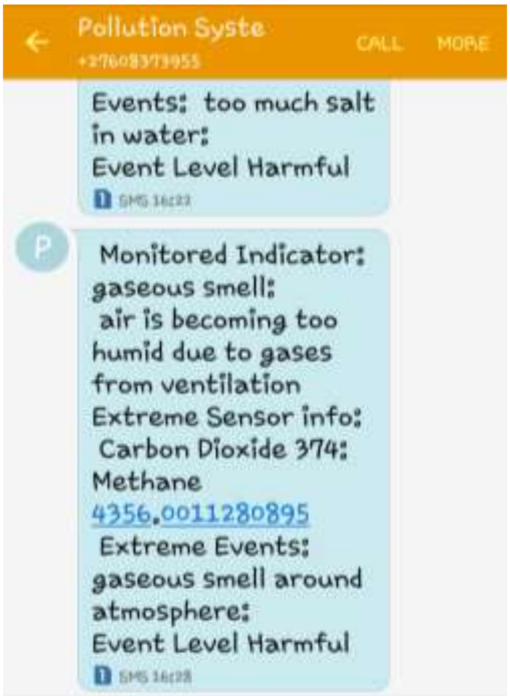


Figure 4.22 ***Output of Current Pollution Data*** **Figure 4.23** ***Alert of Pollution Data***

4.5.7 Data Dissemination from Web Portal

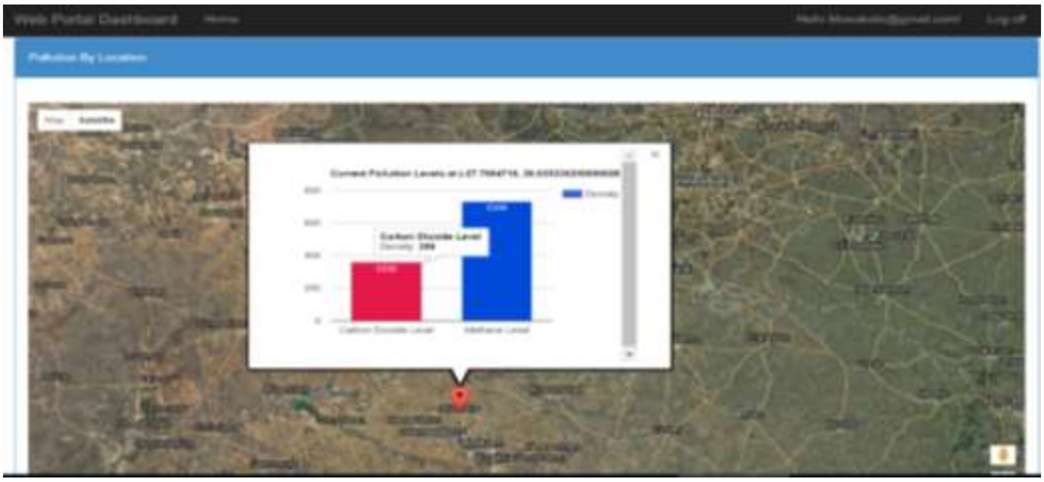


Figure 4.24 ***Graphical View of Pollution by Location***

Fig.4.24 above shows the levels of scientific data of CO_2 and CH_4 on a graphical view.

5. SYSTEM TESTING

5.1 INTRODUCTION

This chapter is about testing the three sub-systems developed for the adaptive environmental management system. The first section is about the mobile application sub-system developed for android phones then followed by the SMS application developed for non-smart phones. Lastly the web-portal sub-system.

5.2 MOBILE APPLICATION

This mobile application is only used by an intermediary person, who is a link between local knowledge experts from the focus group and the researcher. The local knowledge indicators are already pre-stored on MySQL database so what the intermediary person does is to capture observations based on those existing indicators. The experts sit and reach an agreement on the observations of indicators for a day then notifies the intermediary person in order for him to capture them on the application, those observations get transmitted to the database for storage. In order to take care of absence of internet, the application first saves the records to a local SQLite database before transmitting them to the remote database. The second functionality of this application allows the intermediary to send in observed extreme pollution events happening around the community.

5.2.1 Application Installation

The mobile application is uploaded to any android phone from Jelly bean version of 4.4 and above. In our case the application's Android Application Package (APK) which is the package file format used by the Android operating system for distribution and installation of mobile apps and middleware was installed on a Samsung J2 which runs on the Lollipop version 5.1.1. Once installed it appears under the application name; Pollution Management System as shown below.

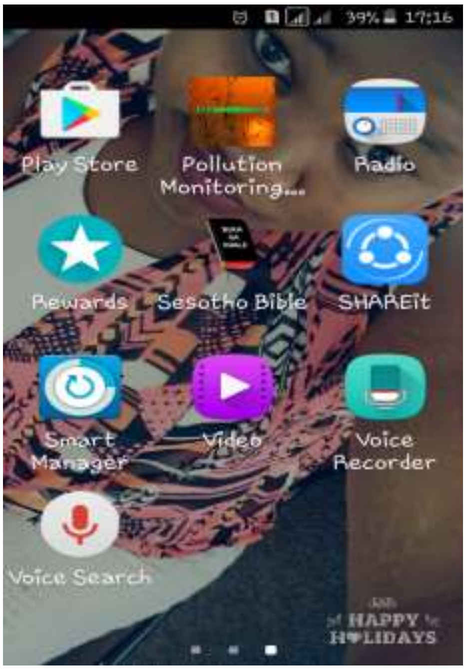


Figure 5.1 ***Icon of Mobile Application***

5.2.2 Application Functionalities

Since only the intermediary person is allowed access into the application, they are provided with already pre-stored credentials which are on the database. The first thing she did was to login to the application as shown by Fig.5.2 after successful login the intermediary person was able to see the Main Menu with two options as indicated in Fig.5.3 below, if she needed to logout then she would press on the black back arrow.

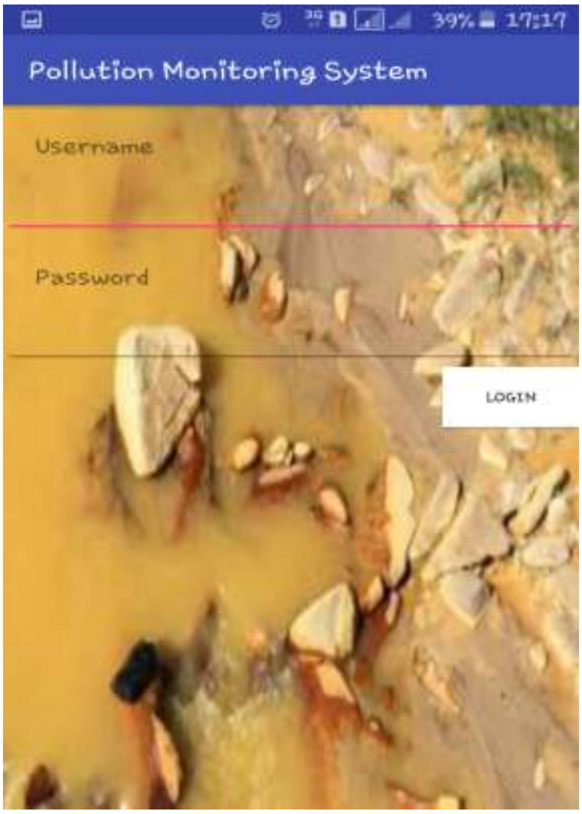


Figure 5.2 ***Login Screen***

Figure 5.3 ***Main Menu Options***

5.2.3 Monitor Pollution Sub-Menu

This captures the local knowledge indicators as observed and agreed by local knowledge's focus group members. For consistency and error reduction, all known indicators are pre-stored in the database. The intermediary person had to select the indicator she needed to observe from the list of indicators by clicking on the down (combo box) arrow as shown in Fig.5.4 below. After selecting the combo box, she wrote the observed information based on the selected indicator then click on the "*UPDATE* "button to save the observations as shown by Fig.5.5.

Figure 5.4 ***Local Knowledge Indicators Selection***

Figure 5.5 ***Capturing of Observed Changes on the Indicators***

The monitor pollution sub menu also includes two other options apart from "*UPDATE*" which stored the observations into the database. The other two options are discussed below:

5.2.4 View Text Data Option

This option allows for textual output of the observed indicators and displays any effects the indicator has on the community members. Again it displays the current monitored sensor data with in the 30 min of the captured observed indicators. Lastly it outputs the extreme events captured as well as date and time as indicated by Fig.5.6 and 5.7 below. Fig.5.6 has extreme events captured within the 30-minute interval and Fig.5.7 shows the effect that acid mine drainage has on local's.

Figure 5.6 ***Textual Data of Pollution and Extreme Events*** **Figure 5.7** ***Textual View of Pollution and the Effect***

5.2.5 View Graphical Data Option

This option allows for graphical output of monitored gases as well as date and time. The first output displaying when clicking on the red marker is the level of carbon dioxide as indicated by Fig.5.8 below. The second output displayed when you click on the marker again is the methane gas level as shown by Fig.5.9. This option is made available by Google Maps.

Figure 5.8 ***Carbon Dioxide Level Output***

Figure 5.9 ***Methane Level Output***

5.2.6 Extreme Event Sub-Menu

Opens the screen below (Fig.5.10) to allow for entry of extreme pollution events. The events have alert stages which are classified as ether Acceptable, Harmful or Moderate and the intermediary person selected one of these by clicking on the down arrow. After making a selection on the kind of alert, the intermediary person keyed in the extreme event and clicked on the “SUBMIT EVENT” button for storage on the database as indicated by Fig.5.11.

Figure 5.10 *Alert Stage Selection*

Figure 5.11 *Extreme Event Capturing*

5.3 SMS APPLICATION

5.3.1 Request Pollution Data

Allows users that are with our system to request pollution data by sending an SMS to the SMS sub-system which includes two words separated by a comma; “plt, data” plt is the abbreviation for pollution it allows the system to recognize that the user is requesting pollution data for that particular day. The Fig.5.12 bellow indicated SMS sent by the user to the system and the response from our sub-system, it shows that our system took only seconds to reply to the user. This is considered reasonable since our system is only a prototype, the OZEKI SMS gateway used with our system is using a Vodacom SIM card. Vodacom is the 1st biggest mobile network provider in South Africa.

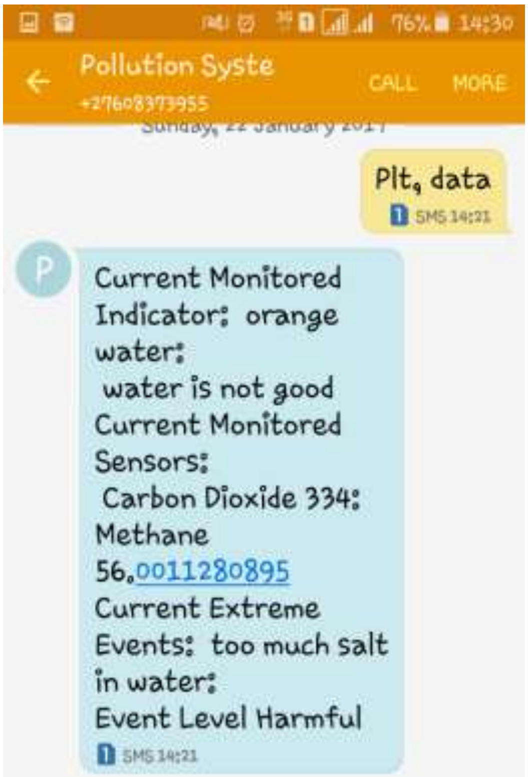


Figure 5.12 ***Request and Response of Pollution Data***

5.3.2 Send Extreme Events

Another option on the SMS sub-system is to allow users to send extreme events they have observed to the system, the system validates that the sender is one of the registered users, if it is not then the message gets discarded. Once the system receives the SMS, the message is disseminated to registered users. The user types in “ext, <the extreme messege>”. ext is the abbreviation of extreme and <extreme message> is the message that the user sends to the intermediary person. Fig.5.13 below shows the SMS sent by the user and Fig.5.14 shows then SMS received by the system. The response time from the sub-system to the users was 39 minutes due to the fact that the SIM card on the Modem communicating with OZEKI SMS gateway had depleted airtime, the researcher had to load airtime in order for the message to go through.

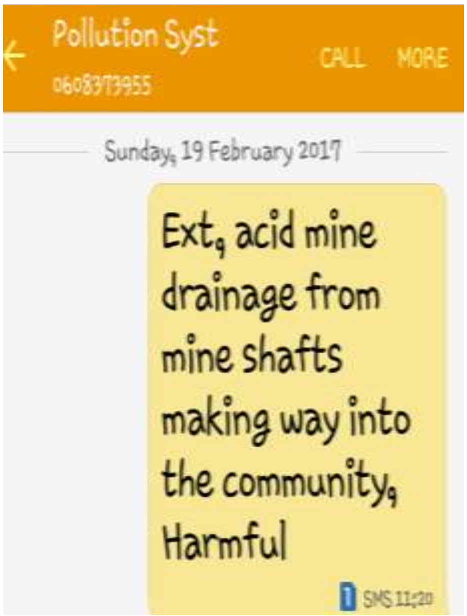
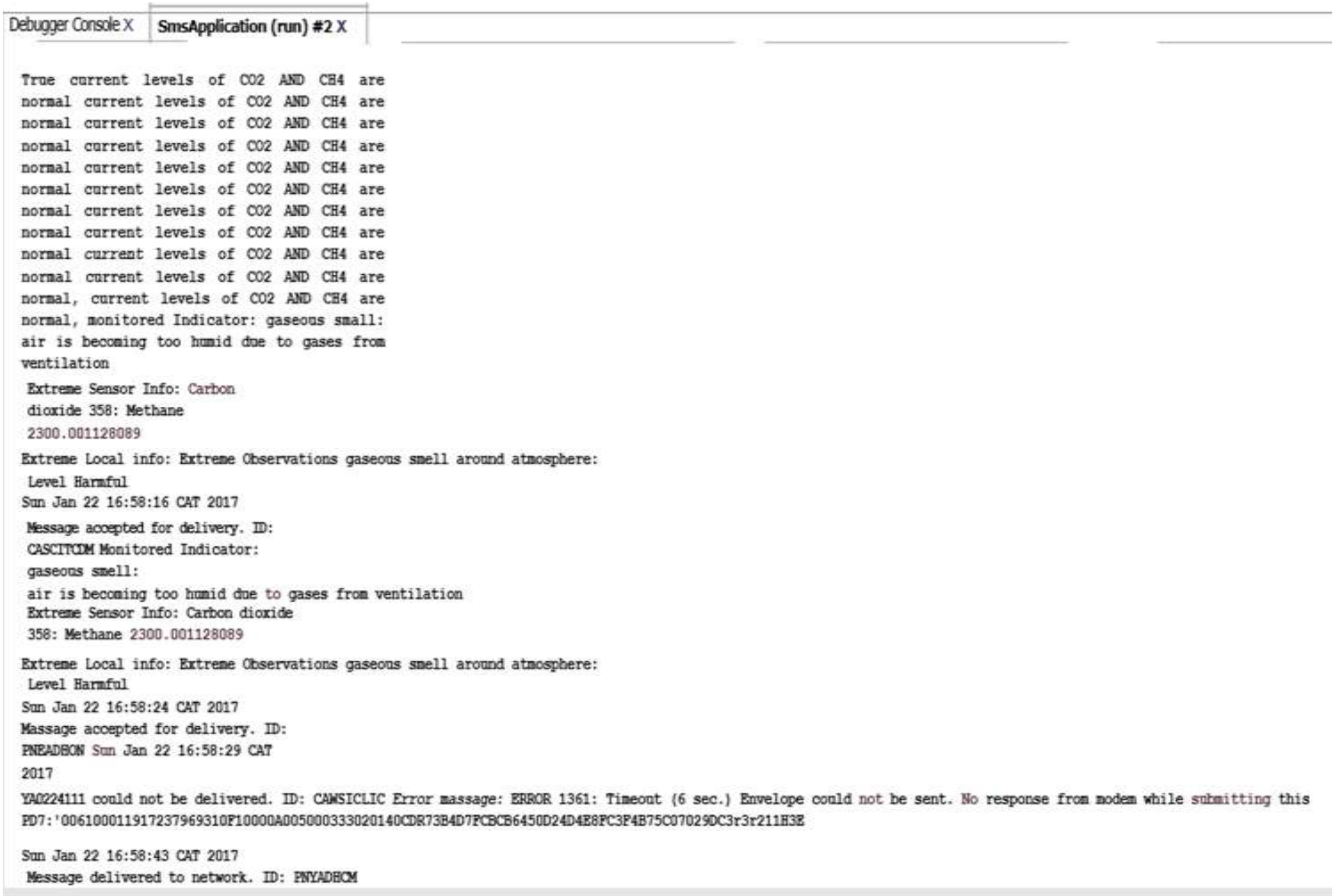


Figure 5.13 ***Notification Sent to the System*** **Figure 5.14** ***Notification Sent to Users***

5.3.3 Alert Messages

Every 30 minutes, the sub-system monitors changes in the database to check the levels of carbon dioxide and methane if they are within limits or have exceeded the limits explained in Chapter 2. Once the sub-system recognizes that the limits are above normal, it sends an alert to all registered users to notify them. The SMS also included monitored local knowledge and extreme events available.



```
Debugger Console X    SmsApplication (run) #2 X

True current levels of CO2 AND CH4 are
normal current levels of CO2 AND CH4 are
normal current levels of CO2 AND CH4 are
normal current levels of CO2 AND CH4 are
normal current levels of CO2 AND CH4 are
normal current levels of CO2 AND CH4 are
normal current levels of CO2 AND CH4 are
normal current levels of CO2 AND CH4 are
normal current levels of CO2 AND CH4 are
normal current levels of CO2 AND CH4 are
normal, current levels of CO2 AND CH4 are
normal, monitored Indicator: gaseous small:
air is becoming too humid due to gases from
ventilation
 Extreme Sensor Info: Carbon
 dioxide 358: Methane
 2300.001128089
Extreme Local info: Extreme Observations gaseous smell around atmosphere:
 Level Harmful
Sun Jan 22 16:58:16 CAT 2017
 Message accepted for delivery. ID:
 CASCITCDM Monitored Indicator:
 gaseous smell:
 air is becoming too humid due to gases from ventilation
 Extreme Sensor Info: Carbon dioxide
 358: Methane 2300.001128089
Extreme Local info: Extreme Observations gaseous smell around atmosphere:
 Level Harmful
Sun Jan 22 16:58:24 CAT 2017
Massage accepted for delivery. ID:
PNEADHON Sun Jan 22 16:58:29 CAT
2017
YA0224111 could not be delivered. ID: CAWSICLIC Error massage: ERROR 1361: Timeout (6 sec.) Envelope could not be sent. No response from modem while submitting this
PD7:'0061000119172379693l0F10000A005000333020140CDR73B4D7FCBCB6450D24D4E8FC3F4B75C07029DC3r3r211H3E

Sun Jan 22 16:58:43 CAT 2017
 Message delivered to network. ID: PNYADHCM
```

Figure 5.15 ***Monitoring Levels of Gases***

The Fig.5.15 above shows how our subsystem was able to monitor the two gases, it continued to monitor when levels were normal, once the levels exceeded the limits the sub-system disseminated the SMS’s to registered users warning them about it.

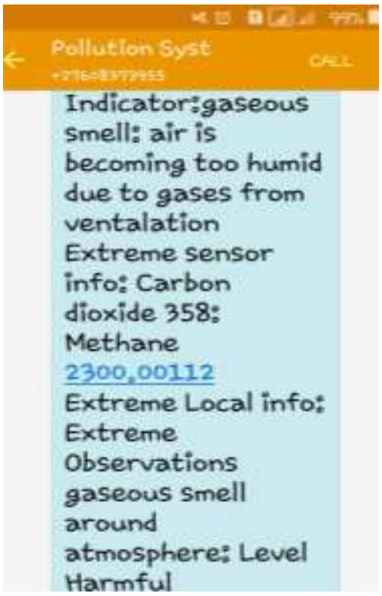


Figure 5.16 ***Alert Message***

Fig.5.16 above shows the alert received by the user from the system.

5.4 Web-Portal

5.4.1 Registration and Login

Our web-portal sub-system allows for users to register into the system; this is control access; it also has the management option if the user need to change his/her password as shown by figures below:

Figure 5.17 ***Register as a New User***

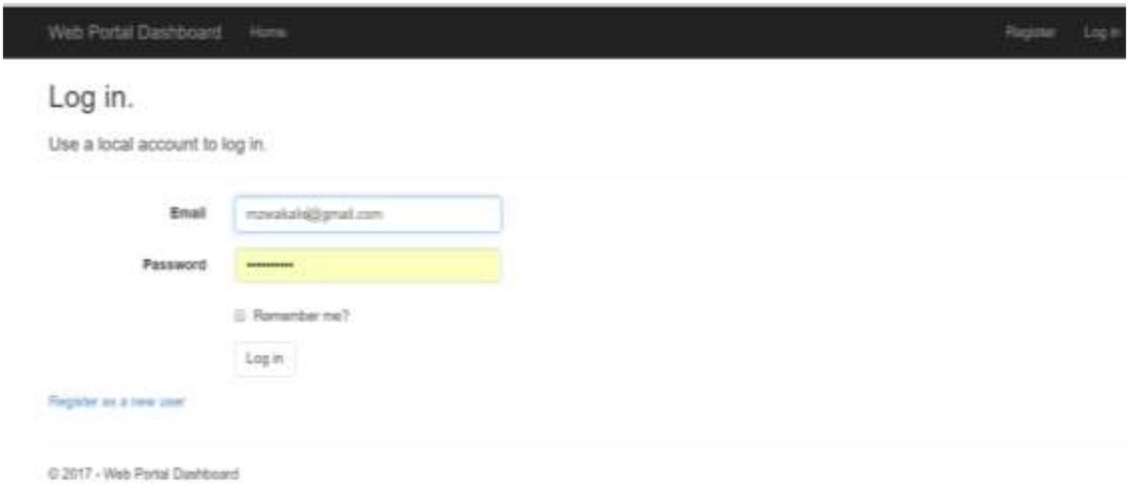


Figure 5.18 ***Login into the Portal***

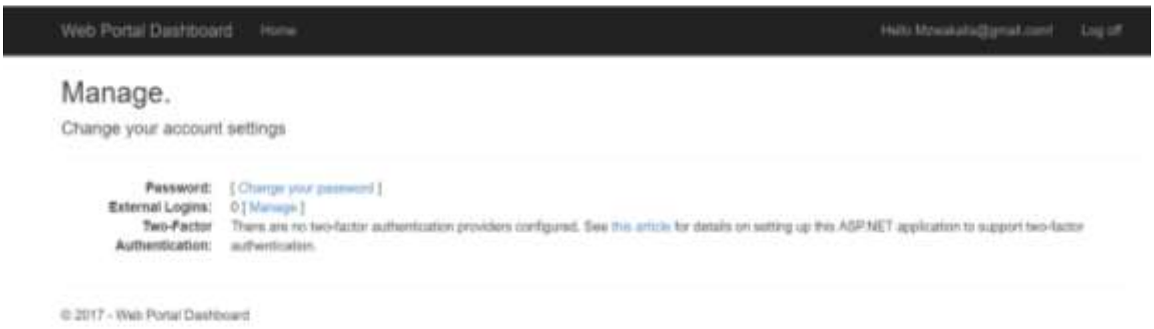


Figure 5.19 ***Manage Account Settings***

5.4.2 Graphical View of Gases

Once the user has successfully logged in, they were displayed with a Google Maps (with the map they had an option to display the normal or satellite map) which has a red marker that indicates the location of the sensor boards, the board is placed near Target mine in Nyakallong Allanridge. When clicking on the marker for Fig.5.20 carbon dioxide was normal since it was not exceeding 350 ppm and Methane gas was above the normal limit 4,400 parts per million(ppm). On Fig.5.21, carbon dioxide was exceeding the recommended limit with 358 ppm. Other experiments were conducted were by both gases were not exceeding expected limits for a number of days, when we took the sensor board near the mine ventilation that takes gases from underground into the surface that is when we were able to see levels exceeding the expected limits.

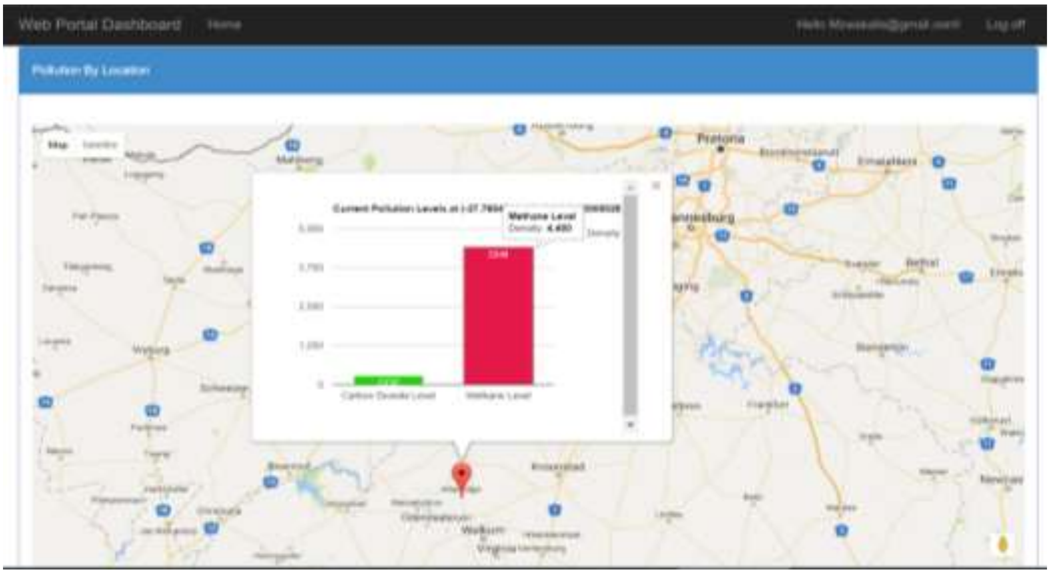


Figure 5.20 ***Level of Methane Gas***

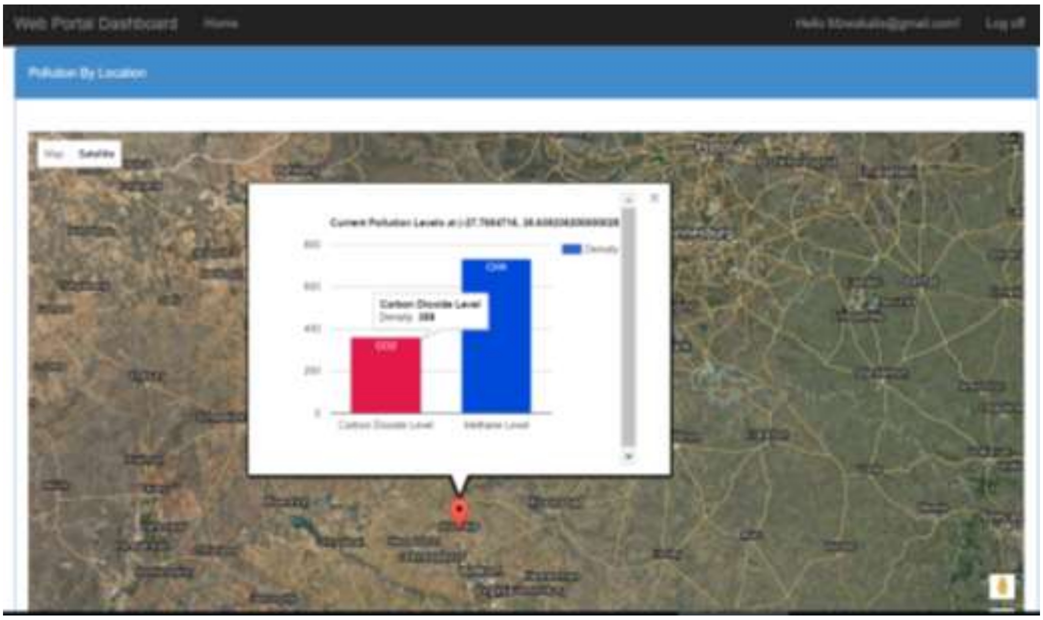
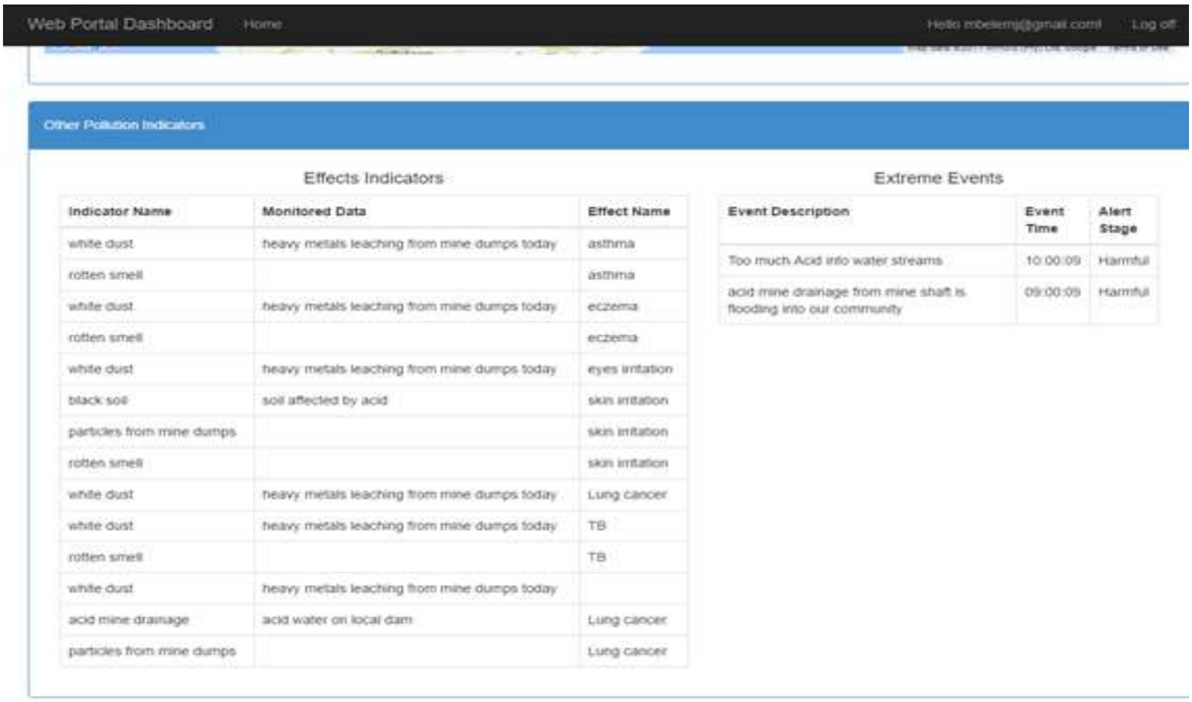


Figure 5.21 ***Level of Carbon Dioxide Gas***

5.4.3 Textual View of Pollution Information

Here the users were able to see all the indicators with their observations as keyed in by the intermediary person (from the mobile application) together with effects associated with each indicator (some indicators do not have effects). The users again are able to see extreme events which were keyed in from the mobile application and stored in the database as shown by Fig.5.22.

The main issue surrounding our web-portal when tested was the use of different browsers, when using Internet explorer, the page had to be refreshed two to three times before the information can be displayed. Further the systems take about 15 seconds before textual data appears, even on Google Chrome. This is one of the issues the researcher needs to improve on in order for the sub-system to be effective and user friendly.



Indicator Name	Monitored Data	Effect Name
white dust	heavy metals leaching from mine dumps today	asthma
rotten smell		asthma
white dust	heavy metals leaching from mine dumps today	eczema
rotten smell		eczema
white dust	heavy metals leaching from mine dumps today	eyes irritation
black soil	soil affected by acid	skin irritation
particles from mine dumps		skin irritation
rotten smell		skin irritation
white dust	heavy metals leaching from mine dumps today	Lung cancer
white dust	heavy metals leaching from mine dumps today	TB
rotten smell		TB
white dust	heavy metals leaching from mine dumps today	
acid mine drainage	acid water on local dam	Lung cancer
particles from mine dumps		Lung cancer

Event Description	Event Time	Alert Stage
Too much Acid into water streams	10:00:09	Harmful
acid mine drainage from mine shaft is flooding into our community	09:00:09	Harmful

Figure 5.22 ***Textual View of Local Knowledge***

5.4.4 Discussion Board

The discussion board allows registered users to engage with one another, the discussion could be based on any issues regarding mine activities as well as the current information the users are displayed with regarding pollution.

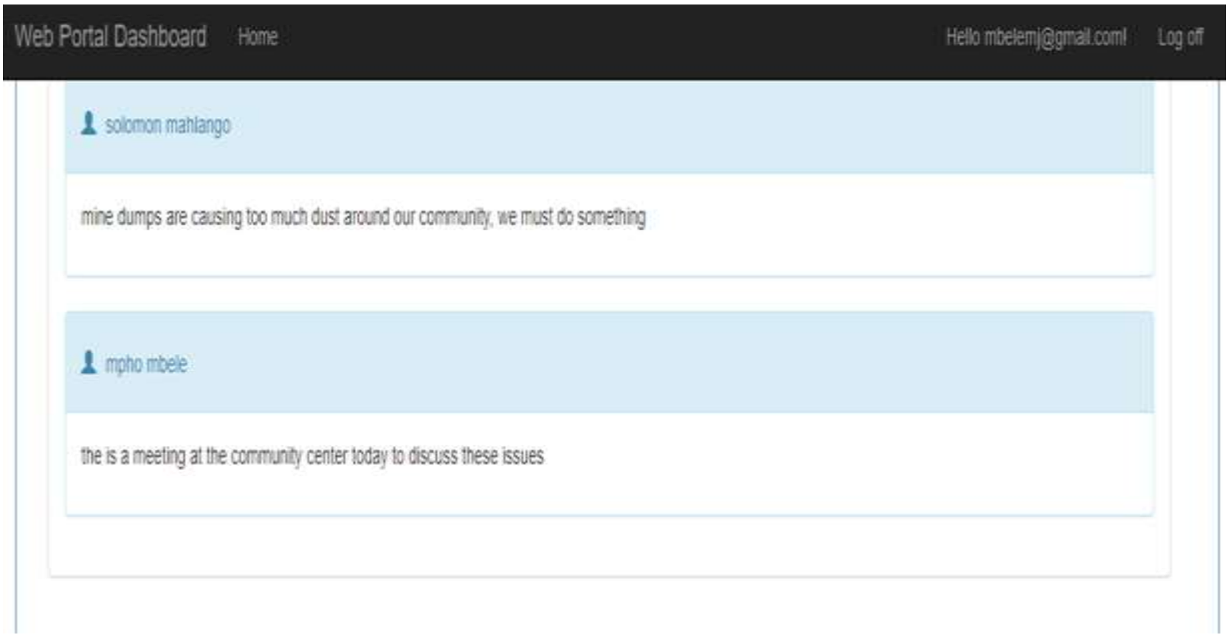


Figure 5.23 ***Discussion Board***

6. CONCLUSION AND FURTHER WORK

6.1 DISCUSSION AND CONCLUSION

Environmental pollution is one of the challenges facing Lejweleputswa due to mining activities in this district and the primary goal of this research was to come up with some steps in the right direction towards sustainable, adaptable and relevant environmental pollution monitoring solution. The main idea the researcher had when developing this solution was to prove that the integration between science and local knowledge is a possibility by making use of technological tools such as FCM for presentation and analysis of local knowledge as well as WSN for collection of scientific data. The use of these two knowledges was to monitor effects of pollution since as they both hold merit to our communities. Currently there is no known solution to the researcher that is as cost-effective and able to monitor environmental pollution by integration of scientific and local knowledge simultaneously. Majority of environmental monitoring systems are expensive and their main focus is on the scientific knowledge part which at times becomes difficult to use or understood by most illiterate local community members most especially the dissemination part. Our solution bridges this gap by not putting too much focus on science but ensuring that local knowledge that has been used by the community for decades to monitor pollution becomes part of the working system. Some systems are still conventional and cannot monitor pollution in small areas such as Nyakallong. To address some of these issues we successfully demonstrated that the more cost effective and sustainable sensor based pollution station could be used to complement the existing conventional pollution stations.

The greatest strength for our solution is ICTs; in terms of, WSNs, mobile phones and FCM technology that were used to glue together these two crucial knowledges' into one monitoring solution. We do acknowledge that monitoring of pollution alone does not call for elimination of pollution around the district but at least it can reduce the impact it has on these communities and accurate information provided by this solution could assist stakeholders to plan ahead in their mitigation and resolution strategies. Moreover, our solution gives the users sense of ownership hence was accepted by users due to the fact that their own knowledge is incorporated within the system. The presence of sensors in this solution allows for capturing of real time and accurate readings on pollution while local knowledge aid in improving the counterbalance, relevance, acceptance, complements the science knowledge and allows for formation of one hybrid knowledge. The systematic capture of local knowledge on pollution by the mobile application both offline and online and storage that we implemented is a remarkable step towards the much needed management and documentation of the uncaptured LK from our communities.

An elaborate process was followed in developing the system. This is described in the chapters presented in this dissertation:

An exploratory research approach was used, both qualitative and quantitative methods of data collection and analysis. The case study of Nyakallong and challenges they face as a result of mine activities were presented. These challenges were received from the case study by making use of interviews and questionnaires. Questionnaires were transformed into FCM's to assist the final indices that were used as the only local knowledge on this study. Some part of the questionnaire was to gain users opinions regarding the three sub-systems created in this research. A report of the findings was presented and assisted in achieving objectives mentioned in Chapter 1.

Another presentation was on the system's architecture, this architecture is the foundation of the system implementation that consists of three components: (1) capturing and storing pollution knowledge; (2) monitoring pollution; (3) and disseminating pollution knowledge. The conceptual framework was also presented and 18 concepts of fuzzy cognitive maps which were used as local knowledge indicators were described. The causal effects that these concepts have on each other were presented by means of matrix table and FCM chart. Another important factor this looked at is the system analysis and design as well as its implementation. We focused on our functional and non-functional requirements our system needed to start operating, of which the requirements were met apart from some hardware requirements such as sensor boards which were not available. The three sub-systems were tested. Namely android mobile application, SMS application and web portal. These sub-systems interact with users as well as disseminate pollution information.

Our solution despite the success it has achieved, future developments are needed to make it more and more adaptable, acceptable, robust and efficient.

6.2 EVALUATION

6.2.1 Acquisition and Representation of Local Knowledge

In acquiring the local knowledge on environmental pollution, the case study of Nyakallong community in Lejweleputswa was conducted. A focus group as mentioned in chapter 3 was formed, consisting of 10 individuals from a local monitoring school which deals with mining impacts around the community. This allowed us to receive information on indicators used to realise and mitigate pollution caused by mining activities. After gathering these indicators from the focus group (by use of interviews and questionnaires), fuzzy cognitive maps usage was explored by making use of the software mental modeler which helps individuals and communities capture their knowledge in a standardized format that can be used for scenario analysis. This software allowed for the definition of important components of a system and define the relationships between these components as well as running "what if" scenarios to determine how the system might react under a range of possible changes. Indicators were extracted from the questionnaire and turned into concepts of the FCM whereby they were able to recognize how they influence one another. Like for an example we were able to recognize that when “particles from mine dumps” as a concept on the map increases (meaning making their way into the atmosphere) it causes “dust” as a concept which results in illnesses such as TB, asthma, eyes and skin irritation. The FCM allowed us to create some scenarios to see what might happen if changes were to happen to these concepts.

6.2.2 Real-Time Monitoring of Pollution.

Libelium Gas sensor boards were used because they are open and support sensors for sensing among many other parameters: (1) carbon dioxide; (2) liquefied petroleum gas, which allowed for us to test methane gas. This gas board was deployed in Nyakallong near Target Gold Mine to test the area for its readiness, the two sensors used were for carbon dioxide and CH_4 to test for methane, once deployed these sensors sent the readings to the Gateway which was also part of Libelium GPRS boards. The GPRS sent the readings to a File Server at Afrihost hosting site. A Java application was developed which compared the levels of these two readings from the gas sensors to the quality standards mentioned in chapter 2. The readings were transferred to the file server every 30 minutes then immediately to MYSQL server which communicates with the Java application.

6.2.3 Adaptive Environmental Management System

In accomplishing this objective, a dynamic and integrated system, made up of three sub-systems was developed. The subsystems communicated with MYSQL database that has data from sensor readings as well as data from local knowledge. Indicators from FCM were keyed into the database after the final FCM was constructed and agreed upon by 10 focus group members who are experts in local knowledge and the researcher. One of the three prototypes developed and tested was an android mobile application. The application is designed to work even in places where there is no or limited Internet connection, it saves data locally then move it to online database once there is internet connection. Further, in order to exterminate irregularities in the local knowledge, the application was designed to work within a focus group and local knowledge indicators are only passed to the system after an agreement among the local knowledge experts from Nyakallong has been met. The mobile application has been in use since January 2017 and the observed LK pollution indicators continue to enrich our prototype. This prototype together with a web portal output the integrated data from sensors and local knowledge both in a textual view as well as graphical view by making use of Google Maps.

Feedback on the system's prototype functionalities

Table 6-1 ***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%

Table 6.1 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 in January/February 2017. 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.

6.3 AN OVERVIEW OF THE STUDY

6.3.1 Research Question 1

To what extend can an environmental pollution management system that integrates local knowledge mitigate impacts associated with pollution?

This question has been clarified in detail in Chapter 5 and 6, the sub-systems ability to interact with users in terms of allowing them to request and submit pollution information as well as alerting them whenever abnormalities occur around the community is a good way to mitigate pollution (refer to section 5.3 and 5.4).

6.3.2 Research Question 2

To what extend can an environmental pollution management system that integrates local knowledge be acceptable by mining communities of Lejweleputswa district?

The majority of respondent(s) from the focus group saw the system as very important for thus making it acceptable for use within the community (refer to Table 6.1).

6.3.3 Research Question 3

How will the adoption of Fuzzy Cognitive Mapping (FCM) in the development of the system in (Question 1) above lead to a dynamic (adaptable to its environment) system?

6.3.4 Research Question 3.1

What is the relevance of fuzzy cognitive maps in ensuring buy-in of the system by community members?

This question was clarified in chapter 3, FCM was used to gather local knowledge from community members. Since it was a new technique used within the community, members were keen in learning how to work with it to see the causal effects indicators provided by them have on each other. As a step towards verifying or validating local knowledge, fuzzy cognitive maps was used to model, analyse and represent this linguistic local knowledge (refer to section 3.6.2).

6.3.5 Research Question 3.2

What is the role of fuzzy cognitive maps in ensuring dynamism (adaptable to its environment) of the system?

This question was clarified in chapter 4, FCM is a useful scientific tool for representation of linguistic data for complex systems; they are applicable in many applications where experts' opinion is very crucial. Local knowledge on environmental pollution by mining activities was collected and presented using FCMs. Pollution indicators were collected and used to come up with FCM Model; the results demonstrate that FCMs provide an efficient solution to the problem of representing local knowledge and that the can be applied in mitigating environmental pollution given scenarios in this case FCM was used to conclude on the final local knowledge indicators used by the subsystems. Scenarios were taken to determine how the system might react to plausible changes to health or environmental indicators within the system (refer to section 4.2.3).

6.4 FURTHER WORK

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 need to be acquired and placed in mining communities. The system only used a gas sensor board which has two gas sensors (carbon dioxide and methane). The required boards have to cater for the above mentioned pollutants. In particular, the water and soil boards of which we did not use at all during our research. What is needed in accomplishing this is the new Gases PRO sensor board from Libelium that includes the particle matter(dust) sensor, a radiation board to detect heavy metals. Smart Water sensor board needs to be acquired which comes with Temperature; Conductivity; Dissolved Oxygen; pH; Dissolved Ions as well as Turbidity sensors, and finally the agriculture sensor board that is able to monitor different parameters such as ambient temperature and humidity, Atmospheric pressure, Pluviometer, Anemometer, Ultraviolet radiation, Solar radiation, Soil temperature, Soil moisture, Leaf wetness, this would aid the communities not just Nyakallong but across the district.

The android mobile application could be extended so that is also used by all community members not just experts, but community members can only request pollution data and see levels of pollution not add any information regarding indicators like the experts do. Moreover, the system has to cater for users who do not understand English, such as users who are familiar with Sesotho (primary language in the district). This can be achieved by inclusion of text- to- speech functionality on our mobile application as well as integration of Google Translator. This system can also include sending emails to users and not only SMSs for users with email addresses.

Our current system does not cater for predictions on pollution, only monitoring with intervals of 30 minutes. Improvements can be made to our system to allow for prediction of pollution for at least two to three days. This could be achieved by integration of machine learning and artificial neural networks into the system. For dissemination of data, improvements can be made on how data is displayed on our web portal on our text output, again inclusion of articles from the monitoring school could also be part of the portal since they report on impacts on mining activities. Coordinates of the location of were sensor boards are placed should be converted to physical locations in order of the users to understand instead of showing them numerical values, this can be accomplished by using Geocoder class of android.

Another issue is regarding the technicality of Waspmote batteries, GPS and GPRS modules which need improvements. Boards were sent to sleep mode when they are not being used but the battery would only last for about 5-6 days. This was resolved by having several fully charged batteries on standby for replacement while we charge the other one. Furthermore, the GPS module could not operate correctly especially in cloudy weather, in this instance the module would not pick up the coordinates of were the board is located. The board needs to be covered mainly during rainy and sunny periods because they get damaged when uncovered and cannot function as needed. These covers cannot just be any cover since it needs to allow the sensor to be able to make its readings with in it, they will have to be specially designed perhaps by electrical engineers who do understand how electrical boards operate and their sensitivity. 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. This could be resolved by use of the XBee Radio and XBee Antennas in replacement of GPRS module.

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APPENDICES

Question 1
What is the main source of environmental pollution in your Area?
Mining
Question 2
What tools do you use to monitor such pollution?
We monitor water pH only by using pH indicator stripes but mostly we do our own observations too monitor pollution
Question 3
What observations do you use or indictors to monitor pollution?
We look at mine dumps, acid mine drainages, waste rocks, soil fertility to specify how they affect our environment
Question 4
How easy is it to monitor pollution by only using your local observations?
It is not really easy, sometimes we do realise the damage after it has been done instead of on time but it is helpful most of the time
Question 5
Do you have a way of reporting about pollution or discussing about pollution around your area?
We have a monitoring school were we discuss the issues regarding pollution

Appendix 1: Preliminary investigation questions

Study for the Development of an Adaptive Environmental Management System: A Participatory Approach through Fuzzy Cognitive Maps

RESEARCH INVITATION LETTER

Dear ______________________,

I am pleased to invite you to participate in an interview to identify the contributors to environmental pollution by mining activities. No more than thirty minutes would be required to complete the interview.

Be assured that any information you provide will be treated in the strictest confidence and your participation will not be identifiable in the resulting report. You are entirely free to discontinue your participation at any time or to decline to answer particular questions.

I will seek your consent, on the attached form, to record the interview and to use the recording in preparing the report, on condition that your name or identity is not revealed, and to make the recording available to other researchers on the same conditions.

Direct any enquiries concerning this study to the **main** Researchers contacts below.

Thank you for your assistance.

Researcher

Central University of Technology, Free State, South Africa

MJ Mbele Tel: +27 73 693 9011 / +27 57 910 3647 or E-mail: mbelemj@gmail.com || mmbele@cut.ac.za

Study for the Development of an Adaptive Environmental Management System: A Participatory Approach through Fuzzy Cognitive Maps

INTERVIEW/QUESTIONNAIRE GUIDE

The purpose of the interview is to identify local knowledge of environmental pollution by mining activities using indicators.

The researcher/research assistant will: -

1. Introduce the interview session by explaining the purpose of the interview, welcome the respondent(s) and make clear why they were chosen.
2. Explain the presence and purpose of any recording equipment and give the option for respondent**(s)** to opt out of recording.
3. Outline ground rules and interview guidelines such as participants can end the interview at any time or refuse to answer any questions,
4. Inform the respondent**(s)** that a break will be provided if time goes beyond 45 munities.
5. Address the issue of privacy and confidentiality and inform the respondent**(s)** that information gathered will be analyzed aggregately and respondent's personal details will not be used in any report. The researcher will also make it clear that respondents' answers and any information identifying the respondent**(s)** as a participant of this research will be kept confidential.
6. Inform the respondent**(s)** that they must sign consent forms before the interview begins.
7. Inform the respondent**(s)** that the interview consists of 15 questions, some with sub sections.
8. Inform the respondent**(s)** how to provide answers to questions by either putting a mark on a check box for optional questions or by giving a short answer for open ended questions.
9. Inform the respondent**(s)** that during or after the interview additional questions can be asked to clarify respondent**(s)** answer.
10. Inform respondent**(s)** that they may choose not to answer a particular question; in that event, he will need to inform the researcher or research assistant.

11. Inform the respondent**(s)** that oral interview will be recorded to ensure responses are captured and transcribed accurately.

12. Inform the respondent**(s)** that they are allowed ask questions before, during and after the interview

13. Go through the process of completing a questionnaire with the respondent(s) through as an example

14. Inform the respondent(s) of follow-up activities and that they should provide their contact details at the end of the questionnaire if they may wish to be involved in the implementation phase of the research.

15. Assist the respondent(s) to properly fill the questionnaires to competition.

16. Collect all the questionnaire from the respondent(s)

17. Close the interview by thanking the respondent(s), maintaining on privacy and confidentiality considerations;

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Questionnaire page 2 and 3

Study for the Development of an Adaptive Environmental Management System: A Participatory Approach through Fuzzy Cognitive Maps

CONSENT FORM

I, the undersigned, confirm that (please tick box as appropriate):

[1]	I have read and understood the information about the research,	☐
[2]	I have been given the opportunity to ask questions about the research and my participation.	☐
[3]	I voluntarily agree to participate in the research.	☐
[4]	I understand I can withdraw at any time without giving reasons and that I will not be penalized for withdrawing	☐
[5]	The procedures regarding confidentiality have been clearly explained to me.	☐
[6]	If applicable, separate terms of consent for forms of data collection have been explained and provided to me.	☐
[7]	The use of the data in research, publications, sharing and archiving has been explained to me.	☐
[8]	I understand that other researchers will have access to this data only if they agree to preserve the confidentiality of the data and if they agree to the terms I have specified in this form.	☐
[9]	Select only **ONE** of the following:	
	• I would like my name used and understand what I have said or written as part of this research will be used in reports, publications and other research outputs so that anything I have contributed to this project can be recognised.	☐
	• I do not want my name used in this research.	☐
[10]	I agree to sign and date this informed consent, along with the Researcher.	☐

______________________	______________	______________
Name of Respondent	**Signature**	**Date**
______________________	______________	______________
Name of Researcher	**Signature**	**Date**

MJ Mbele Tel: +27 73 693 9011 / +27 57 910 3647 or E-mail: mbelemj@gmail.com || mmbele@cut.ac.za

Study for the Development of an Adaptive Environmental Management System: A Participatory Approach through Fuzzy Cognitive Maps

QUESTIONNAIRE FOR DATA AND REQUIREMENTS GATHERING IN THE DESIGN OF DATA REPRESENTATION TOOLS

SCHEDULED FOR DECEMBER 2015

PART A: INTRODUCTION

As a result of living around mining operations and their environmental pollution impacts, the mining communities have been using their own perceptions based on the experience they have regarding pollution to lessen or prevent its impact around them. The Department of Information Technology at the Central University of Technology, Free State is conducting research to identify causal effects of mining activities indicators to environmental pollution outcomes. This research will target data from local community members from Matjhabeng Municipality in Lejweleputswa Free State, South Africa. The results of this research will be used to come up a scientific tool for monitoring environmental pollution, the tool will validate local knowledge received from the community, this knowledge will be helpful in making the tool adaptive to changes around the environment.

You are requested to participate in this valuable research by completing this questionnaire. You are required to put a mark (√ or X) in the check box to select an option or write down a response for open ended questions.

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Questionnaire page 4 and 5

Study for the Development of an Adaptive Environmental Management System: A Participatory Approach through Fuzzy Cognitive Maps

PART B: DEMOGRAPHIC INFORMATION

Q 1 **Names:**

____

(Optional)

Q 2 **Gender? ❑ Male ❑ Female**

Q 3 **Age bracket?**

❑Under 18 ❑18-35 ❑36-45 ❑46-55 ❑56-65 ❑ above 66

Q 4 **Highest Education Level:**

❑None ❑Primary ❑Secondary ❑Post-Secondary

Q 5 **What is the name of your community?**

____

____

Q 6 **What is the main economic activity in your community?**

____

____

Q 7 **How long have you stayed in this community?**

❑ 5- 10 years ❑ 10-20 years ❑ over 20 years

PART C: KNOWLEDGE ON ENVIRONMENTAL POLLUTION

Q 8 **Does mining activities affect your daily lives?** ❑ **Yes** ❑ **No**

Q 9 **Does mining pollute your environment?** ❑ **Yes** ❑ **No**

If Yes,

Do you have systems that monitor this pollution? ❑ **Yes** ❑ **No**

Q 10 **Where do you usually hear about pollution around your community? (You may tick more than one box)**

❑ **Radio/TV** ❑ **Newspaper** ❑ **Mining company** ❑ **Local observations**

❑ **Other? Please specify ______________________-**
____

Q 11 **Do you have confidence in the accuracy of information you hear from above options?**

❑ **Yes** ❑ **No**

Q 12 **Do you have any indicators you use to identify environmental pollution associated with mining activities?**

❑ **Yes** ❑ **No**

If yes, which ones? (You may tick more than one box)

❑ **Mine dumps** ❑ **Acid mine drainage** ❑ **Waste rocks** ❑ **Abandoned shafts** ☐ **Tailing dams** ☐ **Weather seasons**

❑ **Waste rocks** ❑ **Other? ________________**

Q 13 **Do the indicators you specified above help you identify environmental pollution?**

❑ **Yes** ❑ **No**

Q 14 **State an instance (positive or negative) in which you used the indicators stated above to guide your activities decisions. (NB: please state the indicator ad your observations and how it guided your activity)**

PART D: IDENTIFICATION OF INDICATORS AND CAUSAL EFFECTS

Q 15 **Please as per your local perceptions, provide your knowledge of expected outcomes for the following indicators. (NB: State the effect of the indicators to the expected outcomes).**

You should use the following phrases to specify the effect

Increases much

Increases

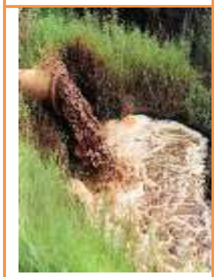
No effect

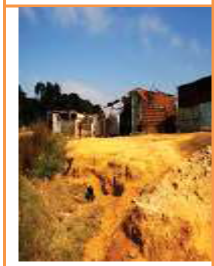
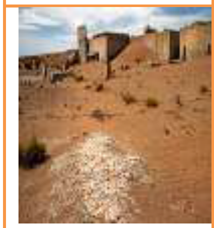
Decreases

Decreases much

To guide you in completing the table an example is demonstrated for you.

Indicator Characteristic	Expected outcomes:						
	Dust	Eye irritation	Outdoor temperature	Plant life	Air moisture	Acid in water	Other ?
 Particles from mine dumps during windy seasons	Increases much	Increases	Decreases	Decreases	Increases	No effect	Coughing Increases

Indicator Characteristic	Expected outcomes: (give a causal effect e.g. decreases/no effect/ increases/						
	Acid in water	Water temperature	Salts in water	Wildlife and Human health	Plant life	Smell	Other ?
 Changes in water color during rainy seasons							
 Acid mine drainage in water							
 Spills from abandoned shafts into water							
 Filling up of tailing dams							

Indicator Characteristic	Expected outcomes: (give a causal effect e.g. decreases/no effect/ increases/						
	Soil acids	Soil temperature	Salt in soil	Soil fertility	Plant life	Soil moisture	Other ?
 Acid mine drainage on soil							
 Waste rocks on soil							
 mine dump impact on soil							
 Mine dumps near crop fields							
Indicator Characteristic	**Expected outcomes: (give a causal effect e.g. decreases/no effect/ increases/**						
	Dust	**Outdoor temperature**	**House cracks**	**Gaseous Smell**	**Acid in water**	**Land degradation**	**Other ?**

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<tr><td>
Release of Gases from mines</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>

heavy machinery and large vehicles required to dig and transport ore</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">**Provide for other indicators not mentioned in this questionnaire**</td></tr>
<tr><td rowspan="2">**Characteristics**</td><td colspan="7">**Expected outcomes**</td></tr>
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</table>

	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
Monitoring using sensors					
Monitoring using local indicators					
Alerts					
Discussing boards					
Locating pollution with Google maps					

Study for the Development of an Adaptive Environmental Management System: A 3AParticipatory Approach through Fuzzy Cognitive Maps

PART E: Adaptive Environmental Management System

The system being implemented will have the following functionalities:

1. **It will monitor pollution using wireless sensors as well as local knowledge mentioned above**
2. **It will allow for users to input any changes regarding local observations of indicators.**
3. **It will allow for users to input any extreme events happening around them**
4. **The system will send out SMS notifications(alerts) to users if and when there are high levels of pollution**
5. **The system will allow users to request data regarding pollution via SMS**
6. **The system will use Google Maps to specify the location of where pollution comes from**
7. **The system will allow the users to discuss their issues regarding pollution on the discussion board**

Based on the system please give a rating:

a) Do you think the functionalities of the system are useful?

b) Would you appreciate receiving pollution alerts when the level of pollution is too high?

	Yes	Maybe	No
SMS Alerts			

b) How important do you think this system is?

Too important	important	Not sure	Less important

Study for the Development of an Adaptive Environmental Management System: A Participatory Approach through Fuzzy Cognitive Maps

PART F: REQUEST FOR RESPONDENT'S FURTHER INVOLVEMENT (OPTIONAL)

Phase II of this study, will involve capturing pollution data using wireless sensor networks and debrief meetings to fill knowledge gaps as well as testing the system during its implementation. Should you be interested to participate, please you are requested to provide your contact details below.

Full Name:	
ID Number:	
Email:	
Your	
Phone Number:	

Thank you very much for your participation

Researcher Sign: Date: