IST-Africa 2016 Conference Proceedings
Paul Cunningham and Miriam Cunningham (Eds)
IIMC International Information Management Corporation, 2016
ISBN: 978-1-905824-55-7

Development of Adaptive Environmental Management System: A Participatory Approach through Fuzzy Cognitive Maps

Mpho MBELE[1], Muthoni MASINDE[2]
[1]*Department of Information Technology, Central University of Technology, Free State, South Africa. Tel: +27 736939011, Email: mmbele@cut.ac.za,*
[2]*Department of Information Technology, Central University of Technology, Free State, South Africa. Tel: +27 515073091, Email: emasinde@cut.ac.za*

Abstract: Mining industries develop environmental management systems/plans to mitigate the impact their operations has on the society. Even with these plans, there are still issues of pollution affecting the society. Though there are ICT-based pollution monitoring solutions, their use is dismal due to lack of appreciation or understanding of the disseminated information. This result in mining communities depending on their own local knowledge to observe, monitor and predict 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, we demonstrate how fuzzy cognitive maps can be used to model, analyse and represent this linguistic local knowledge.

Keywords: Fuzzy Cognitive Maps, Local Knowledge, adaptive system, environmental pollution, scientific knowledge, Lejweleputswa

1. Introduction

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 [1]. Waste from these gold mines constitutes the largest single source of waste and pollution in South Africa [2]. 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 [3]. 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 [4].

The mining industry is responsible for some of the largest releases of heavy metals into the environment, leaving tonnes of mine dumps and acid mine drainages [5]. It has been found that mining communities, prisoners and miners are susceptible to tuberculosis (TB); this is mostly due to mining operations in South Africa (according to the minister of health). Communities living in Lejweleputswa in the Free State province (in South Africa), falls among these mining communities [6]. 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 [7]. 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 [2].

Consequently, pollution remains a serious concern leading to violation of the Section 24 of the Constitution of the Republic of South Africa (Bill of Right), 1996 which states that: "Everyone has the right to an environment that is not harmful to their health or wellbeing; and to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that prevent pollution and ecological degradation; promote conservation; and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development" [8].

South Africa's more resource-endowed municipalities such as Mangaung Metropolitan and Vaal Triangle, use traditional pollution monitoring stations to continuously measure the most important pollutants and report to pollution monitoring systems such as South African air quality information system. However, the number of these stations is usually very small and there is no enough data gathered for evaluation in micro communities like those living in Lejweleputswa. Further, the use and relevance of the current monitoring systems such as South African air quality information system and Blue drop system, 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, monitoring and predicting 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; 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 [9].

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 [10]. It also includes the process whereby knowledge is generated, stored, applied and transmitted to others [10].

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 [11]. 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 [12].

People living in and around Lejweleputswa are all affected by mining activities (that cause pollution); directly or indirectly. They tend to look at seasons of the year; for instance, 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 is formed and affect their water, and soil fertility. Again once a mine is abandoned and not rehabilated, water left in those mine shafts is bound to affect their water and that a certain smell is caused by acid mine drainage as well as release of gases from the mines. All these end up affecting their health, so they have had to learn preventive measures such as; boiling water before use if water is affected by mine drainage as it is believed to lower acidity. To gather the local knowledge on environmental pollution caused by mining activities for validation or verification, the need for fuzzy cognitive maps is required. Once validated, this knowledge could be integrated with wireless sensor network data retrieved from monitored areas within micro communities [21]. This validation makes the system to be community owned and driven, resulting in an adaptive system; an adaptive system involves combining, in a dynamic ongoing process, local and scientific environmental knowledge in the co-management of resources and ecosystems publicizing that knowledge in a well understood manner by our communities [13].

2. Objectives

The aim of this paper is to demonstrate how knowledge from locals (mostly illiterate) living in small communities can monitor and predict environmental pollution using different pollution indicators. To verify or validate this knowledge, an artificial intelligence tool called fuzzy cognitive maps is used for analysis.

To achieve this objective, we first look at the concept of fuzzy cognitive maps and its relevance to environmental management and local indicators verification. Secondly, we look at the various case studies that worked with fuzzy cognitive maps for environmental modelling and management. Thirdly, we describe an FCM model that links environmental pollution to indicator concepts. Lastly, the tests performed on the FCM model (by associating start-up scenarios with subsequent scenarios) are presented.

2.1 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 the introduction 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. The locals know more about the impacts they are faced with each day. One solution around this is for the scientific solutions to cater for knowledge from the affected communities through the integration of the two knowledge systems. This could counterbalance the weaknesses, of the two approaches, 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 well understood by local communities.

2.2 Research question

The research was guided by the research question: “To what extend does the use of Fuzzy Cognitive Maps in modelling and representing local knowledge on environmental pollution ensure that an environmental monitoring system is relevant and adaptive to the affected communities?”

3. Methodology

3.1 Data Collection

Questionnaires were used to gather background information, to determine user’s perceptions on the environmental pollution caused by mining operations and the effects it has on them

The following indicators for observing local knowledge were retrieved from local community members

- Wind: if it is during this season, dust fall is expected from mine dumps to make way into the community;

- Rain: when it rains, heavy metals are leached from the mine dumps and form acid mine drainage that contaminate water streams and soil;
- Release of gases from mines: triggers a bad smell and creates humidity, if a huge amount of methane gas gets released, it is capable of causing explosions and wild fires;
- Closed mine shafts: release acid mine drainage into the community if they are not pumped of water;
- Particles from mine dumps: produce white dust that causes the community to have TB and irritating eyes and skin;
- Heavy metals from mine dumps: affect the fertility of soil and plant life, causes land degradation and acidic water; and
- Acid mine drainage: kill wildlife and causes the water to be acidic and affects soil fertility.

3.2 Data Analysis

Since the data collected from the locals is linguistic by nature, Fuzzy Cognitive mapping were used to analyse these linguistic data and made easier to drive the result. Maps are combined and analysed using Mental Modeller software.

4. Technology Description

Creating Fuzzy Cognitive Maps (FCMs) in consultation with the community allow 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 is a much better way of getting a broader view of how the community understands their environment.

FCMs combines cognitive maps with fuzzy logic; it is used to represent knowledge of complex systems characterized by ambiguity and complex processes [14]. A Cognitive Map (CM) is an oriented graph where its nodes represent notions and its edges 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 [15]. 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.". Fuzzy logic allows computers to more closely parallel the way humans think, identify and solve real world problems. FCMs have proven efficient for solving problems in which a number of decision and uncontrollable variables are causally interconnected [16].

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 [17]. FCMs have been applied in different areas to express the dynamic behavior of a set of related concepts. These maps are powerful tools for analysis and generate simulations in dynamic systems [18]. FCMs may also make it easier for the groups to make decisions together and accept the results. Some of the reasons for using FCM approach 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 [19]. In this study, FCMs are used to model local knowledge among mining communities, to get an understanding on how these communities use their own knowledge to monitor and predict environmental pollution that is caused by mines.

4.1 FCMs Model

Fuzzy Cognitive Mapping approach is a symbolic representation for the description and modeling 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 behavior of a complex system in terms of concepts [19]. 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. Nodes of the graph stand for the concepts that are used to describe the behavior of the system, connected by signed and weighted arcs representing the causal relationships that exist between the concepts. Figure 1 is a simple illustration of FCM Model, example of (figure 2) is an FCM model of local knowledge indicators on environmental pollution: The directed edge E_{ij} from causal concept C_i (in this example it could be a windy season) to concept C_i (which is particles from mine dumps) measures how much C_j influences C_i meaning during windy seasons heavy metals particles fall from mine dumps into the community thus contributing to air pollution. The edges E_{ij} take values in the fuzzy causal interval [–1, 0, 1]. $E_{ij}= 0$ indicates no causality $E_{ij}> 0$ indicates causal increase, C_j increases as C_i increases (or C_i decreases as C_j decreases. $E_{ij}< 0$ indicates causal decrease/negative causality. C_j decreases as C_i increases (or C_j increases as C_i 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 C_i (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 human experience and knowledge on the system under consideration and then integrates the accumulated experience and knowledge concerning the underlying causal relationships amongst factors, characteristics, and components that constitute the system.

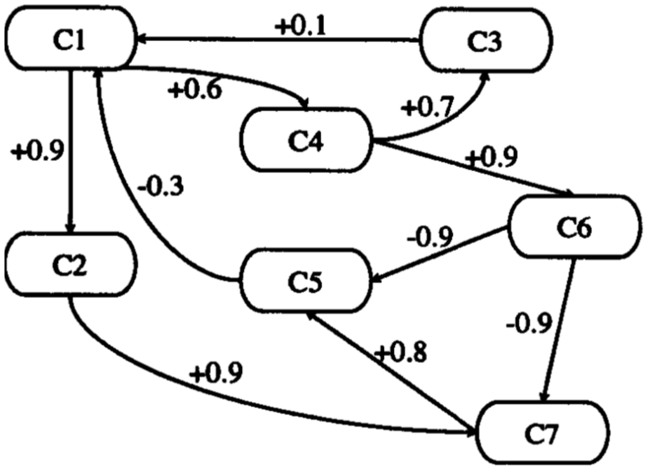

Figure 1: A simple FCM representation

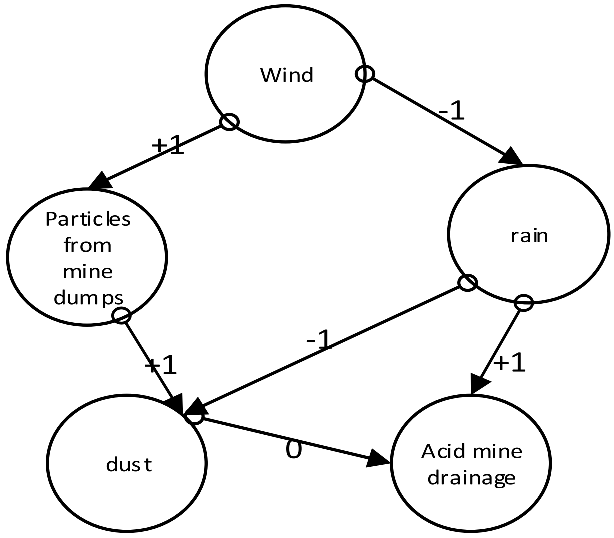

Figure 2: Example of FCM for environmental pollution indices

4.2 FCM Design

FCM are created by experts of the system (in this case the mining communities); in order to retrieve this knowledge from the experts, different methods can be used. Fuzzy cognitive map models can be tested dynamically through simulations where scenarios are introduced and predictions made by viewing dynamically the consequences of the corresponding actions [21]. To collect complex personal knowledge concerning concepts, experts can be interviewed and recordings of interviews will be transmitted into FCMs by a person with FCM knowledge. Alternatively 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 [20] Fuzzy cognitive maps 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 [21]. Fuzzy cognitive maps can be designed using crisp decision trees (well known intelligent techniques that extract rules from both symbolic and numeric data) that have been fuzzified [22].

4.3 FCM application on adaptive/dynamic systems

FCM were originally proposed as a means of explaining political decision making processes, they can also be made with local people, who often have quite a detailed understanding of the environment [17]. Local people input can be important for decision-making about the environment and for the public to accept the chosen solutions since they would have influenced the decisions.

In the case of local people, analysis of environmental modelling and management, the FCMs have found a good number of applications in the world. Initially, FCM was applied as a tool to define management objectives for complex ecosystems. In this case, the FCM model was constructed based on objectives of ecological rehabilitation. The results were interpreted by multivariate statistics. This FCM ecosystem was built for Lake Erie watershed [23]. 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, here local knowledge from stakeholders was used to determine issues affecting the ecosystem negatively, and most stakeholders agreed that lake pollution was the most negative impact as it was mentioned as a concept in most FCM concepts [17]. The multi-step fuzzy cognitive mapping approach analyses how people perceive their environment, and compare and contrasts the perceptions of different people or groups of stakeholders [24]. FCMs have been employed in a number of studies including predicting election results by calculating the percentage chances for a winning candidate, in this study FCM was used with fuzzy logic. FCM was created with information collected from voters with knowledge of their communities, since they knew more about the elected candidates; their knowledge was used to come up with predictions [9]. FCMs were also tested for scientifically verifying weather lore's (knowledge) received from farmers for drought forecasting, this was for farmers in small community around Kwa-Zulu Natal(South Africa) FCMapper was used to model the FCM to come up with scenarios to see how indigenous knowledge on weather can be analysed to predict drought [21].

5. Developments

Important environmental pollution indices and some of their effects from mining communities were created as concepts: rain, wind, acid mine drainage, release of particles from mine dumps, heavy metals from mine dumps, soil fertility, acid in water, soil pH, dust, atmospheric moisture, soil moisture, release of gases, smell, plant life, TB

The causal relationships were represented with weights as: follows: - [strong positive relation = + 1, normal positive relation = 0.5, weak positive relation =0.25, no relation = 0, weak negative relation = - 0.25, normal negative relation =0.5, strong negative relation = -1]. For instance, rain has a strong positive (weight= +1) relation to acid mine drainage, and a strong negative (weight = -1) relation to dust, again release of gases has a normal positive relation to plant life and no relation to wind. The FCM was modelled using Mental Modeler software tool (figure *3* below). The concepts were represented in an adjacency matrix with the values in intersections between concepts representing the relationships (see *figure 4* below). The effects demonstrated on the matrix are interpreted as follows [H+ = +1 , M+ = 0,5 ,L+ =0,25] [H- = -1, M- = -0,5, L- = -0.25] where the is no value there is no effect.

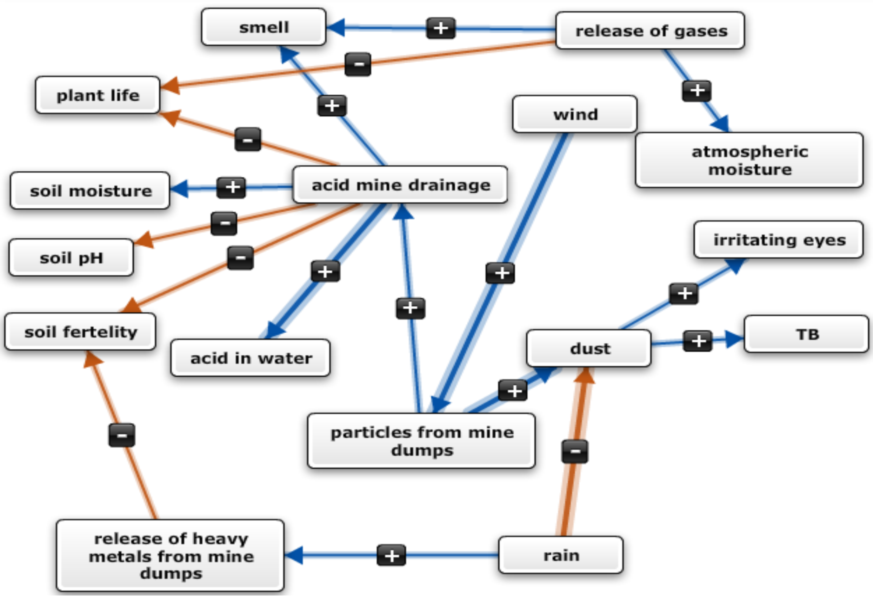

Figure 3 : Fuzzy Cognitive Maps (Concepts)

	release of gas...	atmospheric mois...	smell	plant l...	wind	particles from mine d...	release of heavy metals f...	soil fert...	rain	dust	acid mine...	TB	irritating...	soil...	soil m...	aci...
release of gases		M+	M+	M-												
atmospheric moisture																
smell																
plant life																
wind						H+										
particles from mine dumps										H+	M+					
release of heavy metals from mine dumps								M-								
soil fertelity																
rain							M+			H-						
dust												M	M+			
acid mine drainage			M+	M-				M-						M-	M+	H+
TB																
irritating eyes																
soil pH																
soil moisture																
acid in water																

Figure 4 : FCM matrix

The final deliverable of the entire research is a system that integrates local knowledge analysed by fuzzy cognitive maps with scientific knowledge. In order to further emphasize the importance of this integration, the highlights are provided below:

5.1 Local knowledge together with scientific knowledge

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 [13]. 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 [25]. 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 [26].

Integrating local and scientific knowledge eliminates the diversity between technology and traditional knowledge, it combines two worlds that initially stood on their own, whereas they need each other to be more effective [27][28].The scientific approach is mostly on relevant and applicable to the more developed communities with ease of access and understanding to tools such as smartphones, internet or computer.

In most cases, scientific knowledge is used to address the rural poverty in developing countries and provide necessary incentive needed to transform rural people's lives and increase their welfare, but a conventional and still prevalent view of the relationship between science and the public sees it as consisting of a one-way flow of knowledge and information from scientifically trained researchers to communities, with little direct feedback from local people into research and development [29]. Criticism of this approach, known as the transfer of technology (TOT) model, was prompted by the growing evidence that many development projects were failing and locals were not adopting recommendations thereof [10]. Instead of the non-adopting community member being regarded as inherently conservative or irrational, it was argued that the recommendations and technologies were not always appropriate to the local member circumstances. 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 [10].

There are many different perspectives of what constitutes knowledge or how someone comes to know something; this creates confusion and misunderstanding when attempting to integrate 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 for instance, is advantageous since majority of the mining community members are elderly people who do not have smartphones and access to the internet. Statistics indicate that 77.14 % of the district's population has no internet access, 83.42 % own cell phones, 10.54 % own computers, 75.32 % have Televisions and 69.78 % have radio access [30]. The proposed system also caters for the locals with smartphones and access to the internet by means of web portal and android application.

Literature is awash with examples that demonstrate that integrating scientific and local knowledge is useful. An example include 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 [31]. Again, indigenous knowledge from local farmers in Kenya was integrated with wireless sensor data, this hybrid was used for drought prediction [27][32]. Another 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 [33].

5.2 Proposed integration framework overview

This work is part of a larger project whose main objective is to integrate mobile phones, web portal and wireless sensors in delivering a relevant and micro-environmental pollution monitoring tool that combines local as well as scientific(wireless sensor data) knowledge for Lejweleputswa District.

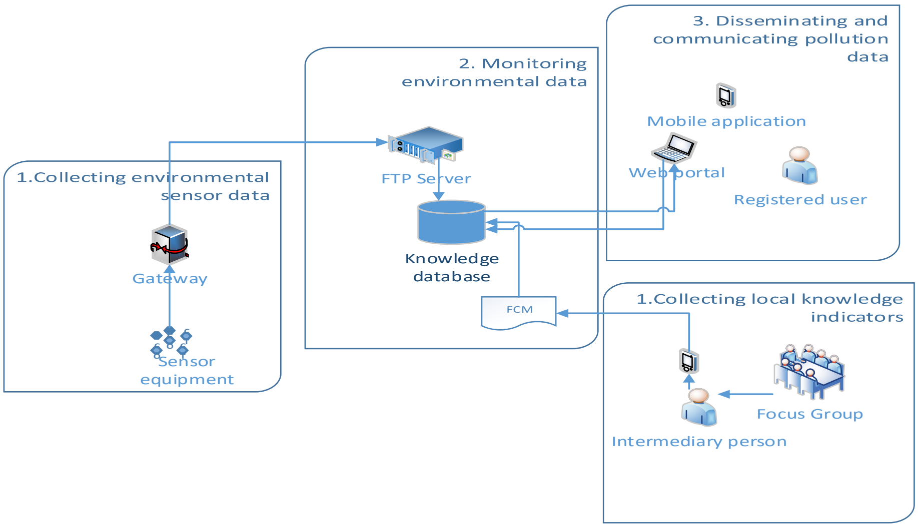

Figure 5: Conceptual Framework

6. Results

Scenarios were undertaken to determine how the system might react to plausible changes to health or ecological components within the system. Furthermore, based on the outcomes of these scenarios, hypothesized environmental management system can be 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, to be evaluated. For instance, as a result of building a shared community model of the environmental management 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 figure below (figure 6) shows a scenario where no indicator was added or deleted. 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 (figure 7 below).

Another scenario was where change of season took (figure 8 below) place 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. The figure below (figure 6) 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 management system and what could be done to reduce the level of impact pollution has in the community.

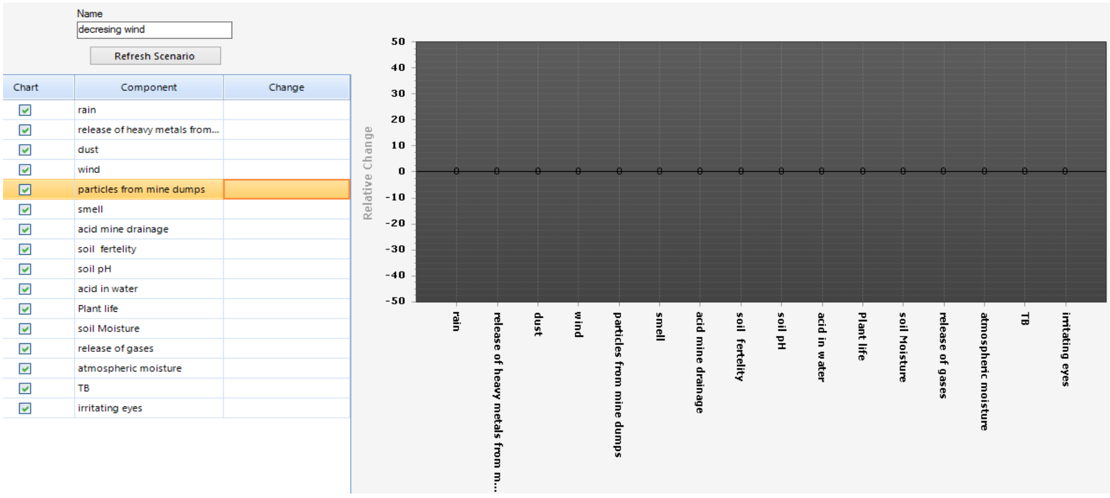

Figure 6: Scenario with no changes made to the concepts

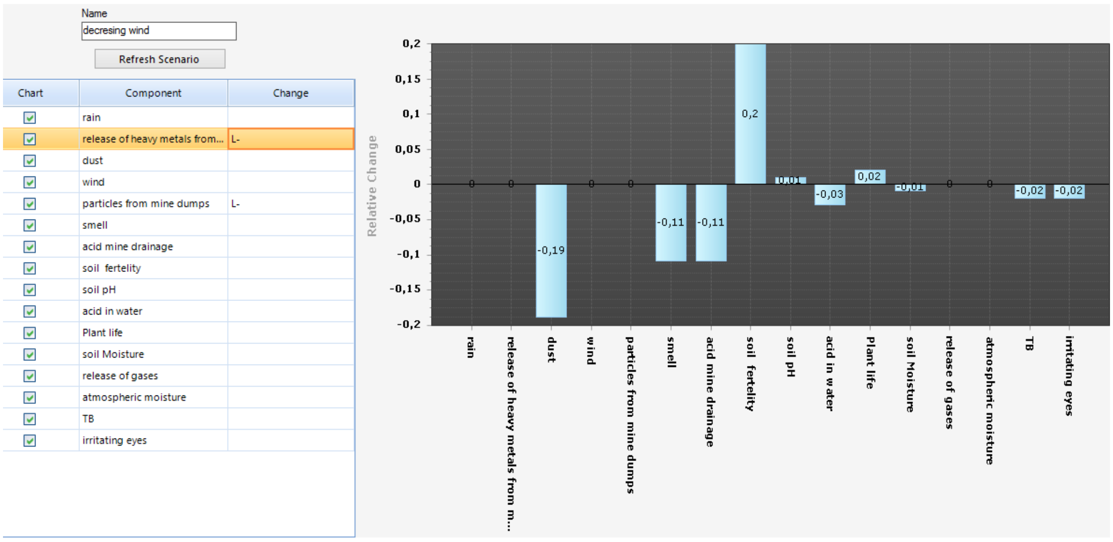

Figure 7: Hypothetical scenario output of reducing the release of heavy metals from mine dumps as well as particles from mine dumps to show in real-time relative change to system components

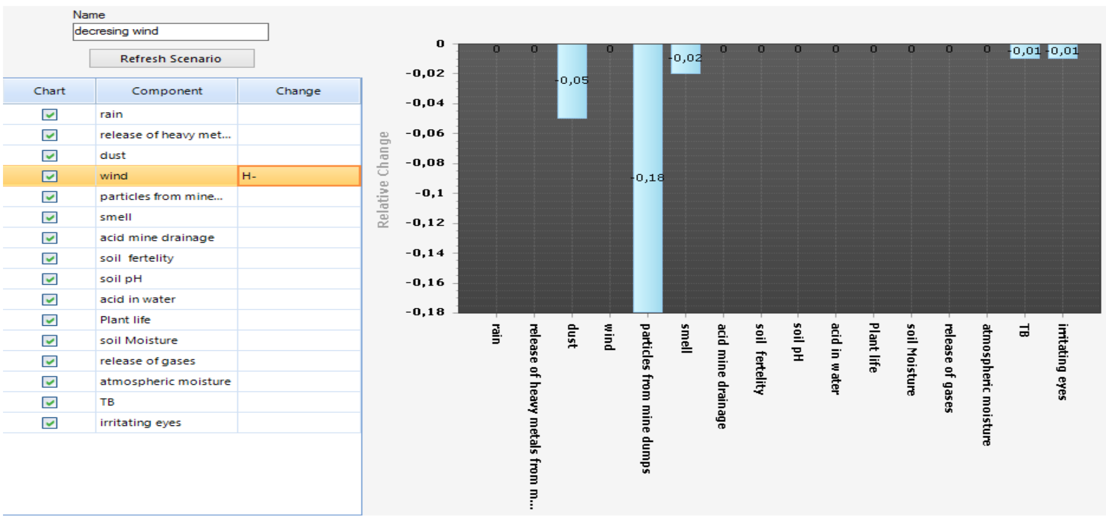

Figure 8: Hypothetical scenario output of season change(were by the is no wind affecting mine dumps)

7. Business Benefits

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. 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 and predict environmental pollution in the current times.

8. Conclusions

FCM is a useful scientific tool for representation of linguistic data for complex systems; they 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 predicting environmental pollution given scenarios. For further research, the current FCM data can be integrated with environmental pollution data collected from wireless sensor nodes in order to produce an adaptive system for complex systems such as global warming or climate changes. Other individual FCMs models targeting noise pollution, radiations, can be constructed and combined with the current FCM as they are also related to impacts from mining activities.

References

[1] Chamber of mines South Africa, 2014. GOLD MINING IN SOUTH AFRICA. [Online] Available at: http://www.chamberofmines.org.za/mining-industry/gold

[2] Oelofse, S.H.H., Hobbs, P.J., Rascher, J. and Cobbing, J., 2007, December. The Pollution and Destruction Threat of Gold Mining Waste on the Witwatersrand: A West Rand Case Study. In 10th International Symposium on Environmental Issues and Waste management in Energy and Mineral Production (SWEMP, 2007), Bangkok (pp. 11-13).

[3] Pathak, C. & Mandalia, H. C., 2011. Impact of Environmental Pollution on Human Future. World Journal of Environmental Pollution, 1(2), pp. 8-10.

[4] Mabiletsa, M. and du Plessis, W., 2001. Impact of Environmental Legislation on Mining in South Africa1. Constitution and Law IV: Developments in the Contemporary Constitutional State, p.153.

[5] Singh, N. and Li, J.H., 2014, March. Environmental Impacts of Lead Ore Mining and Smelting. In Advanced Materials Research (Vol. 878, pp. 338-347).

[6] Motsoaledi, A., 2014.Minister-aaron-motsoaledi-state-nation-address-debate. [Online] Available at: http://www.gov.za.

[7] Azapagic, A., 2004. Developing a framework for sustainable development indicators for the mining and minerals industry. Journal of cleaner production,12(6), pp.639-662.

[8] Republic of South Africa, 1996. Constitution of the Republic of South Africa. [Online] Available at: http://www.justice.gov.za/legislation/constitution/SAConstitution-web-eng-02.pdf

[9] Singh, A. and Devine, M. eds., 2013. Rural Transformation and Newfoundland and Labrador Diaspora: Grandparents, Grandparenting, Community and School Relations. Springer Science & Business Media.

[10] Warburton, H. and Martin, A., 1999. Local people's knowledge in natural resources research. Socio-economic methodologies for natural resources research.

[11] Muindi, K., Egondi, T., Kimani-Murage, E., Rocklov, J. and Ng, N., 2014. "We are used to this": a qualitative assessment of the perceptions of and attitudes towards air pollution amongst slum residents in Nairobi. BMC public health, 14(1), p.226.

[12] Vissers, A., 2010. Perception of air pollution and its impact on human health in the south urban basin: a community perspective.

[13] Olsson, P. & Folke, C., 2001. Local ecological knowledge and institutional dynamics for ecosystem management: a study of Lake Racken watershed, Sweden. Ecosystems, Issue 4, pp. 85-104.

[14] Kosko, B., 1986. Fuzzy Cognitive Maps. Int.J Man-Machine Studies, 1(24), pp. 65-75.

[15] Vascák, J. 2012, "Adaptation of fuzzy cognitive maps by migration algorithms", Kybernetes, vol. 41, no. 3, pp. 429-443.

[16] Maitra, S. & Banerjee, D., 2014. Application of Fuzzy Cognitive Mapping for Cognitive Task Analysis in Mechanised Mines. Journal of Mechanical and Civil Engineering (IOSR-JMCE), 11(2), pp. 20-28.

[17] Özesmi, U. & Özesmi, S. 2003, "A Participatory Approach to Ecosystem Conservation: Fuzzy Cognitive Maps and Stakeholder Group Analysis in Uluabat Lake, Turkey",Environmental management, vol. 31, no. 4, pp. 0518-31.

[18] "Fuzzy Logic; Researchers from College of Engineering Report Details of New Studies and Findings in the Area of Fuzzy Logic (Assessment of learning in environments interactive through fuzzy cognitive maps)", 2015, Computer Weekly News, pp. 518.

[19] Papageorgiou, E.I., 2013. Review study on fuzzy cognitive maps and their applications during the last decade. In Business Process Management (pp. 281-298). Springer Berlin Heidelberg.

[20] Khan, M.S., Chong, A. and Quaddus, M., 1987. Fuzzy cognitive maps and intelligent decision support–a review. School of Information Technology, Murdoch University, Graduate School of Business, Curtin University of Technology, GPO Box U.

[21] Mwagha S.M. and Masinde M, 2015. Scientific Verification of Weather Lore for Drought Forecasting – The Role of Fuzzy Cognitive Mapping. In proceedings of: The IST-Africa 2015 Conference Proceedings, held in Lilongwe, Malawi, 06-08 May 2015. Paul Cunningham and Miriam Cunningham (Eds), IIMC International Information Management Corporation, 2015, ISBN: 978-1-905824-50-2.

[22] Gerogiannis, V. C., Papadopoulou, S., Papageorgiou, E. I. Identifying Factors of Customer Satisfaction from Smartphones: A Fuzzy Cognitive Map Approach. Thessaloniki, 13 – 15 June 2012

[23] Hobbs, B. et al., 2002. Fuzzy cognitive mapping as a tool to define management objectives for complex ecosystems. Ecological Applications*,* 12(5), pp. 1548-1565.

[24] Vanwindekens, F.M., Stilmant, D. and Baret, P.V., 2013. Development of a broadened cognitive mapping approach for analysing systems of practices in social–ecological systems. Ecological Modelling, 250, pp.352-362.

[25] Raymond, C. M. et al., 2010. Integrating local and scientific knowledge for environmental management. Environmental Management*,* 91(8), pp. 1766-1777.

[26] Fensted, J.E., Hoyningen-Huene, P., Hu, Q., Kokwaro, K. and Nakashima, D., 2002. Science and traditional knowledge. Report from the ICSU study group on science and traditional knowledge. Paris, France: International Council for Science.

[27] Masinde, M, 2015, An Innovative Drought Early Warning System for Sub-Saharan Africa: Integrating Modern and Indigenous Approaches. African Journal of Science, Technology, Innovation and Development (AJSTID) Vol. 7, Iss. 1, 2015, Pages 8 – 25

[28] Akanbi, A.K. and Masinde, M., 2015, December. Towards Semantic Integration of Heterogeneous Sensor Data with Indigenous Knowledge for Drought Forecasting. In Proceedings of the Doctoral Symposium of the 16th International Middleware Conference (p. 2). ACM.

[29] Hulme, M., 2009. Why we disagree about climate change: Understanding controversy, inaction and opportunity. Cambridge University Press.

[30] Census, 2011.S Census, 2011. Statistical release (Revised). [Online]
Available at: http://www.statssa.gov.za/

[31] Tengo, M. et al., 2014. Connecting Diverse Knowledge Systems for Enhanced Ecosystem Governance: The Multiple Evidence Base Approach. AMBIO*,* pp. 579-591.

[32] Muthoni Masinde & Antoine Bagula (2011): ITIKI: bridge between African indigenous knowledge and modern science of drought prediction, Knowledge Management for Development Journal, 7:3, 274-290

[33] Gobin, A., Campling, P., Deckers, J. & Feyen, J., 1998. Integrated Toposequence Analysis at the confluence zone of the River Ebonyi headwater catchment. *Catena,* pp. 173-192.