Achieving Smart Resource Management for Better Disaster Management using Space-based Technology in Lowershire Basin, Malawi

Donnex CHILONGA
Mzuzu University, P/Bag 201, Luwinga, Mzuzu 2, Malawi
Tel: +265 882756490/+265 99937102, Email: donnexc@gmail.com

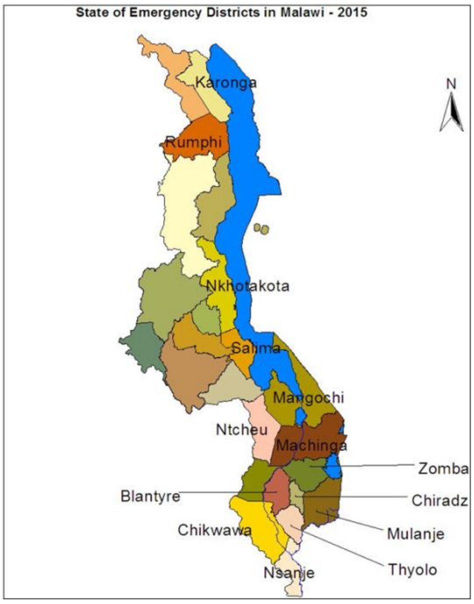
Abstract

Advancements in new geo-spatial technologies across the globe are seen as a way to advance the decision-making process of first responders before and after a disaster. Unstructured disaster information and an infrastructure for accurate disaster information may be accessed and retrieved successfully through present new and important tools. Such tools could help improve the performance of disaster prediction in any country across the world. This paper illustrates a method based on incorporation of space and terrestrial technologies that aims at providing vital information to first responders for smart management of floods in Loweshire Basin, Malawi.

Keywords: Lower Shire Basin, Mtayamoyo, Geo-spatial technologies, GlobalPositioning System (GPS), Geographic information system (GIS),Flood control, Malawi

Introduction

Natural hazards affect humans' life and health at different scales in time and space, causing a dramatic impact on the sustainability of society, especially those that are vulnerable because of their geographic location or poverty.. Natural disasters are a characteristic of life of the first decade of the twenty-first century (Stallo, Ruggieri, Cacucci, & Dominici, 2013). Events such as droughts, floods, earthquakes and cyclones have rendered human beings destitute. In January 2015, Malawi was struck by floods. Preliminary reports indicated that the floods left at least 174,000 people displaced, with 62 deaths and 153 people missing. The situation prompted the President of the Republic of Malawi to declare a State of Emergency on 13th January in 15 districts (out of the 28) of Nsanje, Chikwawa, Phalombe, Zomba, Blantyre, Chiradzulu, Thyolo, Mulanje, Balaka, Machinga, Mangochi, Ntcheu, Salima, Rumphi and Karonga (Weekend Nation Newspaper, 7th October 2015).



Considering the degree of damage highlighted above, and that which is to come in the subsequent rainy seasons, it is therefore necessary to study and develop very efficient tools in order to forecast these natural disasters, which can cause economic and social damage anywhere in the world. Presently, development initiatives by the United Nations, with the support of the European Community are underway for the prediction and early warning of such events (Buscema & Ruggieri 2011). To provide an early warning of an impending flood and improve the first response calls for the provision of proper and prompt information to first responders.

During such disastrous events and in anticipation of the same, Stallo et al, (2013) emphasize that when developing tools for forecasting natural disasters, floods in particular, one needs to consider the kind of information that must be made available to first responders to improve their response. At the same time, one needs to think of the mechanism of how the information can be distributed in an efficient way?

In addressing the first consideration (i.e. of the kind of information to be provided) Lunduka, Phiri, Kambani & Boyer (2010), in their final research report on *Malawi Disaster Risk Reduction and Climate Adaptation for CORDAID*, identified the following to be the needed information that must be available to civil protection committees vis-à-vis first responders:
Information about people, goods, infrastructure i.e. roads and buildings and their likelihood to collapse; about relief centres where disaster victims can go for safety; about how relatives of victims can be contacted; updated disaster and safety maps specifying vulnerability and new risk levels and the likelihood of occurrence of another catastrophe. Such information is vital as it helps rescue and technical assistant teams to be more efficient and timely in their relief attempts. The information may be made available through satellites, sensors and radio frequency identification (RFID) technology (Stallo et al, 2013).

The information described above can thus be collected and distributed using a Swarm network operated between Navigation Communication (NavCom) and Earth Observation (EO). This system, if properly customised, can be used in various kinds of disasters because it adopts a modular approach (Muraleedharan & Osadciw, 2000).

Therefore, this paper describes Swarm intelligence, an integrated system that aims at providing information to civil protection workers and first responders for early warning of a disaster and immediately after it. Such information will, among others:

a. Enhance local understanding of natural disaster processes;
b. Assist first responders in preparing for such and related events i.e. Early warning instruments for preparedness; Emergency recovery and relief;
c. Assist in monitoring of potential dangerous situations globally and locally, using satellite technology (Constellation of Small Satellites for the Shire River Basin integrated with Global Navigation Satellite System [GNSS] solutions) instead of the unreliable traditional solutions;
d. Help in the development of a real-time, web-based geographic information system (GIS) database platform which can be easily accessed for monitoring and risk mapping.

1.1. Swarm intelligence and its Uniqueness

Swarm intelligence is the joint behaviour of a group of social insects, for example ants, birds, where the agents (insects) communicate in the system either directly or indirectly using a distributed problem solving approach. This approach supports an optimised routing design, avoids stagnation, and prevents centralization of the network nodes. Since the routing in wireless network is never static, this intelligent sensor approach provides a solution to dynamic and distributed optimisation problems, making the network to be robust, flexible, decentralized, coherent and self organized (Kennedy & Eberhart 2001).

Swarm agents (ant agents) are randomly placed over the network and consist of three features; Pheromone Level, Transition Probability and the Tabu-Lists. Real life ants deposit a chemical substance called pheromone, which serves as a trail for the other ants to follow. The ant system mimics this pheromone deposition by laying pheromones depending on both energy level at the sensor node and the distance among the different pheromone levels {one node to another} (Muraleedharan & Osadciw, 2000).

Thus, Swarm intelligence system is unique and ideal in providing information to civil protection and first responders for early warning of a disaster and immediately after it because:

1. It distributes data intelligently and innovatively through a NavCom and EO integrated system to activate a swarm network (Heinzelman, Kulik, & Balakrishnan, 1999);
2. It smartly identifies the useful data to be gathered, recorded and distributed. This data can be real-time and/or survey-based. Real-time data can be localized or globalised data. Both local and global data can be obtained from the earth's ground surface (i.e. through sensors, RFID technology smartphone, local and geological data); and from the sky (i.e. through global positioning system (GPS) and synthetic aperture radar [SAR], local and global meteorological data) (Stallo et al, 2013).
   Survey based data can be obtained from interviews of the victims of the disaster, geological survey, historical survey and data collected from call centres, from first responders and from the general community (Stallo et al, 2013).
3. It is a contemporary and advanced NavCom systems design for emergency rescue applications (Kennedy & Eberhart 2001). It involves the utilization of space systems and terrestrial enhanced wireless/mobile radio systems for the management of first phases of a disaster. The use of extremely high frequencies (EHF) [30–300 GHz], for example W band frequencies [75–110 GHz] makes swarm intelligence system idyllic for developing a highly secured applications such as Public Safety and Disaster

Recovery (PSDR). It further gives assurance of reliable communications with minimal susceptibility to jamming, and the ability to achieve smaller, secure, high bit-rate beams by using small-sized antennas (Stallo et al. 2010).

2. Space-Based technologies and data collection

It is necessary to emphasize that one of the most important and controversial uses of satellites today is that of monitoring the Earth's environment and the processes that take place on it. The ability to forecast weather, climate, and natural hazards, environmental monitoring and ecological issues depends critically on these satellite-based observations. Based on this data it is possible to gather satellite images frequently enough to create the model of the changing planet, improving the understanding of Earth's dynamic processes and helping society to manage limited resources and environmental challenges. Satellites that observe the Earth to collect scientific data are usually referred to as “Earth observation satellites.” Sometimes the interpretation of their data has been controversial because the interpretation is difficult (Rustamov, Salahova, Zeynalova &Hasanova, 2012).

Recent studies on the use of space-based technologies have established that the measurements of earth surface changes can better be achieved through the use of GNSS networks that are aided by augmentation systems, such as the European Geostationary Navigation Overlay System (EGNOS) and EO. The use of these techniques, combined with other disciplines, can generate reliable hazard maps and define disaster preparation zones (Barbera, Stallo, Savarese, Ruggieri, Cacucci, & Fedi, 2010). Further, earth surface deformations such as changes in the properties of the crust (density, electrical resistivity, changes in groundwater levels, and other geochemical precursors) can also be detected by EO. EO data can be derived from GNSS observations, high-resolution satellite images, SAR, and photogrammetry (Dominici et al. 2011).

GNSS data can thus be obtained from permanent stations (PS) scattered within the area of interest. Each station is equipped with a receiver, a geodetic antenna and a local acquisition system guided by specific software for storage of all positioning data and continuous compilation of all satellite signals and the recording of their code and phase over time. This information is broadcast in real time by the transmission and receiver hardware (H/W) of the permanent station. The data recorded can be accessed by authorized users during the last hours for the entire area covered by the service. Combined with high-resolution satellite images (i.e. both multi-spectral and panchromatic), this information can therefore be used during both the pre- and post-emergency periods.

2.1. Data Collection and Information exchange

Data collection and the exchange of information are easily performed through the development of swarm network architectures, wireless networks, and advanced sensors (Engelbrecht 2005). For an improved decision quality and for a reduction in answer time, the information needs to be spread widely throughout the area of interest. The use of the ‘‘swarm intelligence’’ means using autonomous individuals who are able to cooperate with others and adapt to environmental variations. In the context of a disaster such as floods, a swarm network can help during the prediction phase and initial rescue period.

Muraleedharan & Osadciw (2000) identified three desirable functional properties of the system-level procedure of a swarm sensor network, which include:

- robustness: ability to operate even during disturbances from the environment or the malfunction of its individuals. The loss of an individual is immediately compensated for by another one. After all, the coordination process is decentralized.
- flexibility: ability to perform tasks of different natures.
- scalability: ability to work under a wide range of group sizes and support a large number of elements without considerably impacting the performance.

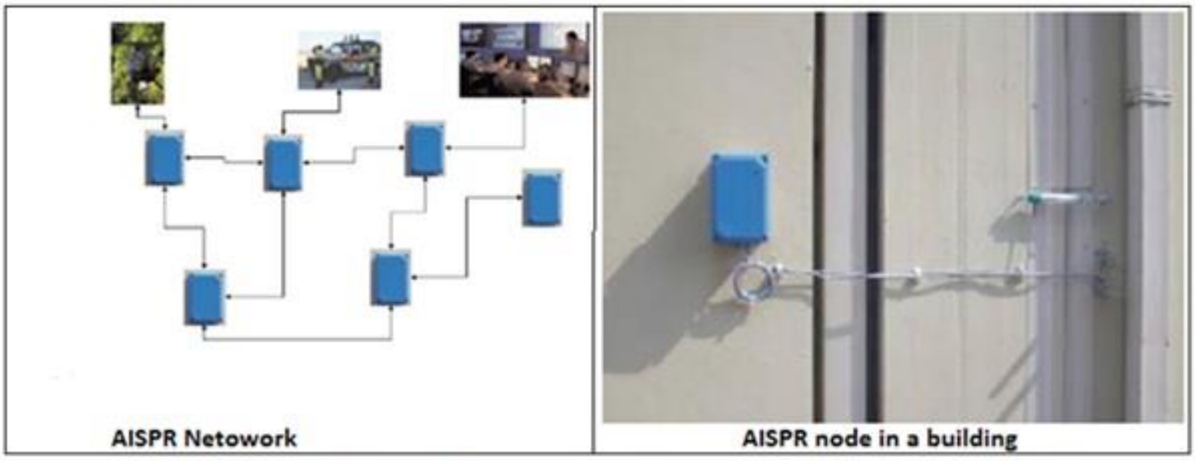
Coordination mechanisms are also considered here, two of which are: self-organization and stigmergy. The former is crucial where real systems are made up of real nodes (i.e., robots, sensors), because it is the basic standard behind the autonomous behavior of the agents. Hence, a swarm system does not need a central station driving the whole system because it is able to configure itself. Self-organization therefore is the capability of a system to change its organization in response to environmental changes without explicit external commands. The latter, in real applications, is a behavioural property of the agent/node to modify the environment in which it is moving, in order to reach a specific goal (Kennedy & Eberhart 2001).

These coordination mechanisms are important because they simplify the organization of the swarm toward the final formation. As such, agents are aware in real-time of their position and can move according to it (Hadim & Mohamed 2006). This important role is played by the positioning accuracy and precision of GNSS.
To this far, two projects have been developed by the URTV:

i. Software-to-Hardware Pen-Drive (SoHa-Pen) project: where GPS receiver is associated with each agent for specific performance during the phases of risk (Stallo et al. 2010; Barbera et al. 2010).
ii. Satellite Compass project: based on the use of the satellite compass for very accurate monitoring of strategic buildings or infrastructures.

3. Adaptive Information System for Prevention and First Response (AISPR)

AISPR is an independent and all-encompassing network of varied multi-sensor nodes that provides an infrastructure that is able to route the proper information to a diversified people in the proper places and time during a disaster, provided that the users are enabled and have proper authorization at that particular moment. The major aim is to assist the operator in making the best decision. Such distribution ensures reliability, availability, promptness, and security (Kennedy & Eberhart 2001).



Adopted from Stallo, Ruggieri, Cacucci and Dominici, 2013

The density and adaptive ability of the nodes, coupled with the serverless architecture, make the AISPR system intrinsically robust and able to function even with some malfunctioning nodes. Each node is fitted with sensors that give disaster and structural information of the place where it is deployed. The information that is given is time stamped and georeferenced to give a detailed and updated picture of the territory.

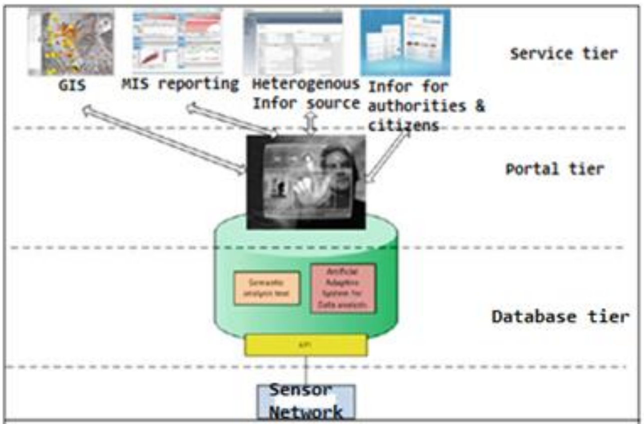
Apart from being used as a database for collecting data on events that occur in a building before an event, AISPR may also act as a provisional communication network where data among different nodes can be exchanged.
Data processing can thus be done using the following main tools:

- artificial adaptive systems, such as artificial neural networks. These manage extremely complex information so as to predict disasters and to create maps of disaster risk factors;
- data collection and exchange of information.

Upon completion of data processing, a coordination service needs to be provided by institutional organizations so that all these great amounts of data are used in a proper way to guarantee effective coordination and synergy among players such as civil protection, police, and rescuers etc. Via an online portal, information related to floods can be collected and disseminated

3.1. System Architecture

The system is based on a three-tier architecture consisting of the database tier, the portal tier, and the service tier.



System Archtecture

Adopted from Stallo, Ruggieri, Cacucci and Dominici 2013

The system architecture consists of:

- an online portal;
- a system database comprising of semantic analysis tools and an artificial adaptive system for data analysis;
- the sensor network;
- the GNSS and SAR networks;
- GIS/management information system (MIS) subsystems.

Online forums are used to collect both structured and unstructured heterogeneous data coming from different sources (for example, sensors, GPS, satellite measurements, folk information, interviews, etc.). Structured data are directly stored in the database, whereas unstructured data are processed using a semantic analysis tool and structured in order to be stored. Scientific measurements conducted in the area of interest will also be stored in the database. Online forum subscribers will be able to access the database in order to find useful information. The database will be supported by an artificial adaptive system for data analysis that could be managed by selected users (Stallo et al, 2013).

3.2. Exemplifying the usability of the architecture in Lowershire Basin

To illustrate the capabilities of the architecture for improving first-response activities, let us analyze a typical flood disaster scenario at Mtayamoyo bridge on Mtayamoyo River in Nsanje district, Malawi.

3.2.1 Illustration stage 1

Immediately after the floods on Mtayamoyo River, a sizeable amount of new data, coming from the affected area, is made available and stored in the database:

- ‘‘on-ground’’ sensor data;
- airborne or satellite sensor data (Note that this information is not current but is usually a few hours old);
- direct information from people affected by the event made available through online forum, phone calls or text messages to civil protection;
- information from the civil protection workers in the flooded area.

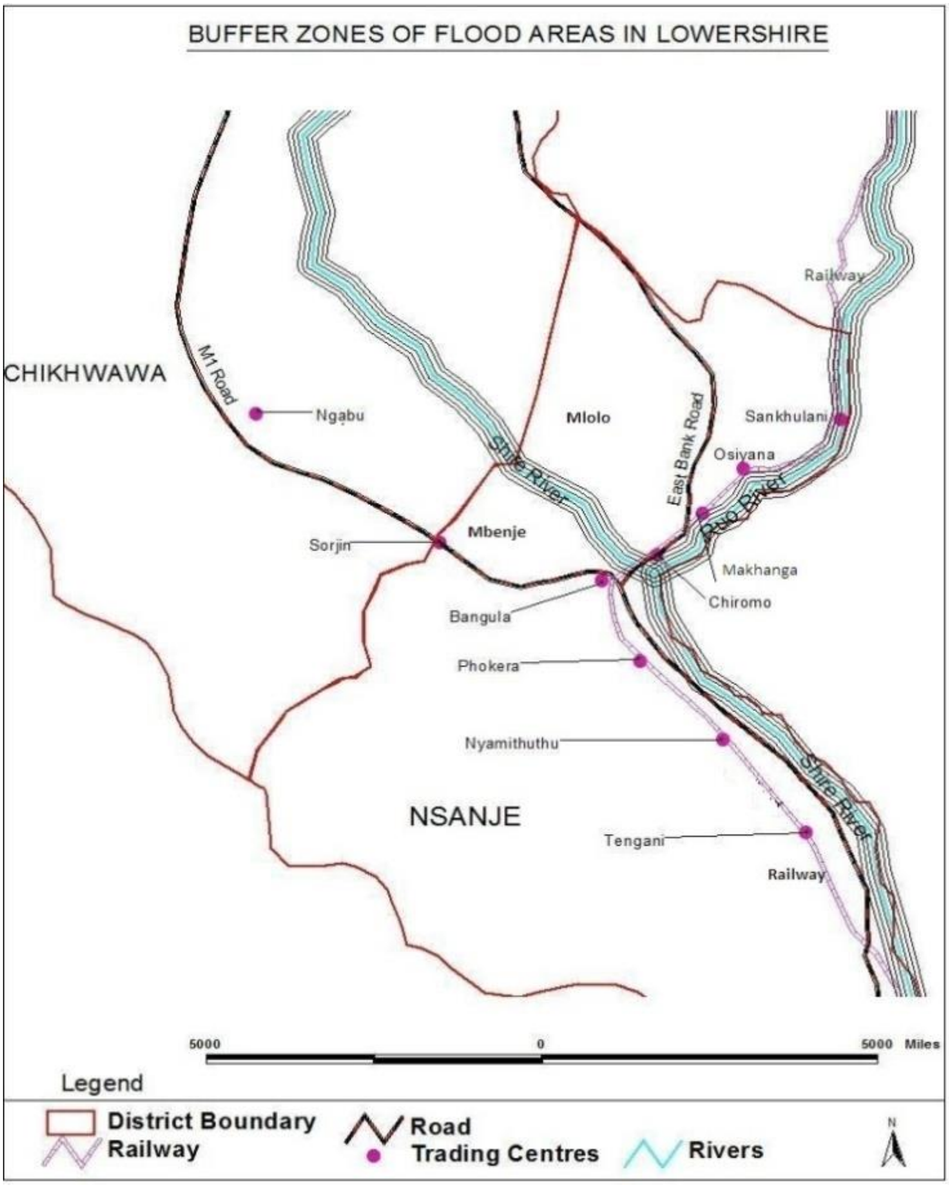
3.2.1 Illustration stage 2

Think of the collapse of Mtayamoyo bridge on Mtayamoyo River in Nsanje district. This event can be recorded by sensors deployed at various strategic positions around the bridge and by people living in the surrounding area; hence, the following data should be available:

- A direct call with a message such as, ‘‘Mtayamoyo bridge on Mtayamoyo River, at Bangula Trading Centre, is swept by water.’’ Using semantic analysis, the following information about the bridge can be stored:
  - Geographic coordinate position of the bridge (i.e. Longitude and Latitude)
  - Possible road obstruction
  - Possible presence of victims
  - Possible presence of displaced people around the bridge
  - Possible damage to property of displaced people
  - Estimate of volume of water recorded by a sensor near the swept bridge

Such data could be directly forwarded to civil protection workers in the area and be used to improve first-response activities. At the same time, the data coming from the civil protection operators can be used to update the data stored into the database together with data coming from airborne/satellite sensors.

All of this updated information is of utmost importance not only in the coordination of disaster response activity but also in enhancement of rebuilding and restoring activities.



4. Conclusion

It is established in this paper that advancements in new geo-spatial technologies across the globe is a means to advance the decision-making process of first responders during a disaster. Such tools could help improve the performance of disaster prediction tools developed in any country in the world. This paper has illustrated a system based on incorporation of space and terrestrial technologies that aims at providing vital information to first responders for smart management of disasters. By creating a database that can be used to gather and exchange information about disasters (drought or flooding, in particular) coupled with previous experiences of first responders, people involved in disasters, and scientists studying disaster processes, will allow for better preparedness and more effective responses to the future disasters, thus improving the capability to restore normal activity after a crisis situation.

References

Barbera, S., Stallo C, Savarese, G,, Ruggieri, M,, Cacucci, S&Fedi F. (2010) A geo-referenced swarm agents enabling system: theory and demo application. *IEEE First*

International Conference on Systems, Modelling and Simulation (ISMS 2010), 27–29 Jan 2010, Liverpool, England, pp. 100–104.

Buscema, M, & Ruggieri, M. (2011) *Advanced networks, algorithms and modeling for earthquake prediction*. Aalborg : River Publishers,

Dominici, D., Galeota, D., Gregori, A., Rosciano, E. & Elaiopoulos M. (2011) Using new techniques of geomatic and structural control in the old city center of l'Aquila after the April 6, 2009 earthquake. In *Proceedings of Joint International Symposium on Deformation Monitoring*, Hong Kong 2–4 2011

Engelbrecht, A. (2005) *Fundamentals of computational swarm intelligence*. n.p. Wiley

Finkl, C.W. (2000) Identification of Unseen Flood Hazard Impacts in Southeast Florida through Integration of Remote Sensing and Geographic Information System Techniques. *Environmental Geosciences* 7, pp. 129-136.

Heinzelman W, Kulik J, & Balakrishnan H. (1999) Adaptive Protocols for Information Dissemination in Wireless Sensor Networks, *Proc. 5th ACM/IEEE Mobicom Conference (MobiCom '99)*, Seattle, WA, August, 1999

International Conference on Computer Modelling and Simulation, (2010) 12th Emmanuel College, Cambridge University, (UK), 24–26 Mar 2010, pp. 104–109

Kennedy, J. & Eberhart R. C., (1995) Particle Swarm Optimization, *Proc of the 1995 IEEE International Conference on Neural Networks*, 4, IEEE Press, pp. IV: 1942-1948.

Kennedy J, Shi Y. and Eberhart R.C.,(2001) *Swarm Intelligence*, San Francisco :Morgan Kaufmann Publishers.

Lunduka, R.W, Phiri, M.A.R.,. Kambani,C. & Boyer, C. (2010) *Malawi Disaster Risk Reduction and Climate Adaptation Research for CORDAID* – Final Report. Lilongwe : Episcopal Conference of Malawi.

MacDonald, Thom. Learning from the January 2015 Floods – Adoption of Malawi Disaster Management Policy, *Weekend Nation* Newspaper of 17th October 2015, p.1.

Muraleedharan, R, & Osadciw L.. A. (2000) Sensor Communication Network Using Swarm Intelligence, In 29th *International Conference Computers and Industrial Engineering*, Nov. 2000.

Rustamov, R.. B.., Salahova, S. E, Zeynalova, M. H. & Hasanova, S. N. (2013) *Earth Observation – Space Technology*, Baku, Azerbaijan

Stallo C, Cianca E, Mukherjee S, Rossi T, De Sanctis M. & Ruggieri M (2010) IR-UWB for multigigabit communications beyond 60 GHz. Telecommunications Systems, 55:1

Stallo. C., Barbera, S., Savarese, G, Ruggieri, M., Cacucci, S. & Fedi, F. (2010) A geo referenced swarm agents enabling system for hazardous applications. UK Sim *International Conference on Computer Modelling and Simulation*, 12th Emmanuel College, Cambridge University, (UK), 24–26 Mar 2010, pp. 104–109

Stallo, C, Ruggieri, M, Cacucci, S.& Dominici, D. (2013) Using Space-Based Technology for Smart Resource Management during Disaster Early Warnings. Springer Journal 2013-2014.

Tarikhi, P. (2010). The role of new Earth observation technologies on monitoring disasters and mitigating the effects; specific focus on radar techniques,In: *Proceedings of the International Conference on Geoinformation Technology for Natural Disaster Manageme Management* (GIT4NDM), Chiang Mai, Thailand, 19-20 October 2010.

Biography

Donnex Chilonga is a research scientist cum geographer with specialty in the utilization of space-based technology in solving current social problems. He has been teaching at University level since 2012. Throughout his 4-year span Donnex has built a reputation for developing space-based scientific models tailored for disaster management. Together with his colleagues in the Geography and Earth Science department of Mzuzu University, Donnex is a lead on building a model for communication for first responders in times of flooding in Malawi. Donnex' academic background includes a PGD in Remote Sensing and GIS and BA (Geography) obtained from African Regional Centre for Space Science and Technology Education, Obafemi Awolowo University and Mzuzu University respectively. His interest in environmental protection for equitable use saw Donnex obtaining a Diploma in Law from the University of Malawi's Chancellor College.