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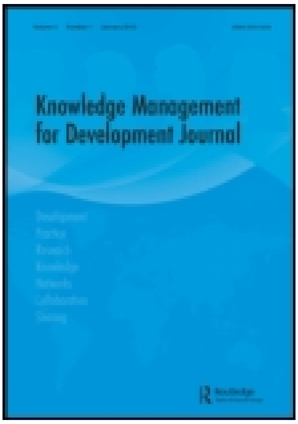

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ITIKI: bridge between African indigenous knowledge and modern science of drought prediction

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Droughts are the most common type of natural disaster in Africa and the problem is compounded by their complexity. The agriculture sector still forms the backbone of most economies in Africa, with 70% of output being derived from rain-fed small-scale farming; this sector is the first casualty of droughts. Accurate, timely and relevant drought predication information enables a community to anticipate and prepare for droughts and hence minimize the negative impacts. Current weather forecasts are still alien to African farmers, most of whom live in rural areas and struggle with illiteracy and poor communications infrastructure. However, these farmers hold indigenous knowledge not only on how to predict droughts, but also on unique coping strategies. Adoption of wireless sensor networks and mobile phones to provide a bridge between scientific and indigenous knowledge of weather forecasting methods is one way of ensuring that the content of forecasts and the dissemination formats meet local needs. A framework for achieving this integration is presented in this paper. A system prototype to implement this framework is also presented.

Introduction

Droughts have become chronic in Africa, especially in Sub-Saharan Africa (Szöllösi-Nagy 1999), where they have resulted in an unending problem of food insecurity. Of all natural disasters, droughts cause the greatest havoc in Africa; for example, they accounted for over 90% of people affected by natural disasters in Africa between 2000 and 2009 (Red Cross 2010). Second on the list were floods (a related disaster), which accounted for a mere 8%. Further, during the same period (2000–2009), Africa contributed 46% of all droughts recorded. The complex nature of the onset and termination of droughts has led to it acquiring the title ‘the creeping disaster’ (Mishra and Singh 2010), and unlike other disasters, the effects of drought continue to be felt long after its termination and it spans all aspects of human life. Agriculture still remains one of the key pillars of most economies in Africa. The situation is made worse by the fact that a major proportion of crop production (over 70%) comes from vulnerable rain-fed small-scale farming operating in fragile environments that are ecologically, geographically and economically marginal (ISDR 2008). Farmers in this category would definitely benefit from drought prediction solutions that are designed with their involvement. These farmers are interested in customized forecast information that can reliably inform them about onset, cessation and intra-seasonal variations in order to reach decisions such as what, when and how to plant/harvest.

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The most commonly used form of forecasts used in most countries in Africa is the seasonal climate forecast (SCFs). Research (Ziervogel and Opere 2010) has shown that SCFs are too supply-driven and are too 'coarse' to have relevance at a local community level. The terminologies (e.g. below and normal level) and formats used do not make much sense to most farmers. Furthermore, the modes of dissemination (websites, radio/television broadcasts and print media) do not reach the targeted audience. Consequently, farmers continue to rely on forecasts that are based on indigenous knowledge, namely indigenous knowledge forecasts (IKFs). It is in realization of this fact that an initiative (http://www.africa-adapt.net/aa/ProjectOverview.aspx?PID=PUXVdbXh9bM%3D) aimed at integrating SCFs with IKFs was piloted in Kenya. The integration was geared towards maximizing the strengths of the two types of forecast (SCFs and IKFs), and by extension improving the adoption of weather forecasts by small-scale farmers. Started in September 2008, the project brought together meteorologists and the Nganyi indigenous knowledge forecasters to build 'reconciliations' between SCFs and IKFs. The reconciled forecasts were carried out for seven seasons between 2007 and 2011 and results disseminated through the locally available (existing) communication channels, such as chief *barazas* and churches. The outcome of the project was rated 'very good' by the two parties.

There has been a sharp increase in publications in the area of indigenous knowledge (IK) in Africa, especially in South Africa, where tens of research projects are funded through the National Research Foundation (Loubser 2005). Despite this encouraging trend, publications in the category of weather/droughts/climate-variation prediction are still rare. For instance, in a recent study (Njiraine *et al*. 2010) on IK research in Kenya and South Africa, publications directly and indirectly touching on this topic were found in the agriculture and environment categories. Unlike other categories, such as culture (with 41.2% of papers for Kenya and 31% for South Africa), these (agriculture and environment) categories had minimal representations of 11.5 and 7.5% for agriculture and 12 and 6.9% for environment (the percentages are for Kenya and South Africa, respectively). Generally, publications on IK on drought/weather management in Africa (ISDR 2008, Ziervogel and Opere 2010, Ajibade and Shokemi 2003, Roos *et al*. 2010, Steiner 2008, UNEP 2011) reveal that communities in Africa use more or less common approaches to predicting drought and weather. They observe the changing seasons as well as lunar cycles (shape/position of the moon and patterns of the stars). They also observe the natural environment (behaviour of animals/birds and the appearance of certain plants) and, like modern weather forecasters, IK also involves studying meteorological parameters such as air temperature, cloud colour and direction, and wind direction. Religious beliefs and myths also contribute greatly to African IK on drought prediction. For example, rainfall is seen as gift from the gods and lack of it as a curse. For example, in reference to the 2011 drought affecting some parts of Mbeere in Kenya, residents were often heard saying; 'we do not know what God wants with us!' Other examples of IK are that: (1) mating of animals is a sign that there is going to be plenty of rain (Roos *et al*. 2010); (2) the birth of many girls is a sign of a good season and more boys is a sign of a bad season (Mugabe *et al*. 2010); and (3) a wind blowing to the west will bring rainfall in an hour (Ajibade and Shokemi 2003).

IK on droughts in Africa has two sides – prediction as well as spelling out elaborate coping mechanisms. When drought strikes the Mbeere people, the women specialize in weaving baskets using (mostly) locally available materials and then travel to Central Kenya (Kikuyu Land) to exchange them for cereals. Similarly, the women among the Bastwanas of South Africa engage in creative activities such as making clay pots for water storage as well as entrepreneurial purposes (Roos *et al*. 2010). African communities also have common food preservation practices such as meat drying and stockpiling; these are meant to ensure food availability during shortages.

Although IKFs and SCFs have more differences than similarities, participatory solutions designed around information and comunications technologies (ICTs) can be used to make SCFs complement IKFs. This is because, although IKFs are localized and more adapted to the farmers' context, this knowledge is threatened by phenomena such as climate change, population growth and urbanization. SCFs act as a complement by introducing aspects such as global weather parameters. The big question then becomes: how then do we bridge the gap between these two diverse sciences of weather forecasting? The authors present one such solution – ITIKI (Information Technology and Indigenous Knowledge with Intelligence) – a framework that integrates IKFs and SCFs using mobile phones, wireless sensor networks and intelligent agents. *Itiki* (pronounced e-ti-ki) is the name given to a kind of a bridge made from sticks and wires for crossing rivers by the Mbeere people in the eastern part of Kenya.

Literature review

Definitions of terminologies

Droughts

Warwick (1975) defines drought as 'as a condition of moisture deficit sufficient to have an adverse effect on vegetation, animals and man over a sizeable area'. As in the definition given in Wilhite and Glantz (1985), this implies three categories of drought: agricultural, hydrological and meteorological.

1. *Meteorological* drought is a period of abnormally dry weather sufficiently prolonged for the lack of water/rainfall to cause serious hydrological imbalance in the affected area (Huschke 1959).
2. *Hydrological* drought is a period of below average water content in streams, reservoirs, groundwater aquifers, lakes and soils (Rosenberg 1979).
3. *Agricultural* drought is a climatic exception involving a shortage of precipitation sufficient to adversely affect crop production or range of production (Panu and Sharma 2002); the latter is a manifestation of meteorological and hydrological droughts.

Among other things, drought prediction plays a critical role in the planning and management of the now scarce water resource. Drought prediction should provide information on drought *duration*, *severity* and *location* in absolute time (initial and termination time points).

Indigenous knowledge

The terms that are used to describe IK are 'local knowledge', 'indigenous knowledge', 'indigenous traditional knowledge', 'indigenous technical knowledge', 'traditional environmental knowledge', 'rural knowledge' and 'traditional ecological knowledge'. In Steiner (2008), indigenous/traditional knowledge is described as the knowledge of an indigenous community accumulated over generations of living in a particular environment. It is traditional cultural knowledge that includes intellectual, technological, ecological and medical knowledge. Indigenous knowledge can be defined as a body of knowledge built up by a group of people through generations of living in close contact with nature (Johnson 1992). Some authors have attempted to differentiate these terms, especially ‘local’ and ‘indigenous’. In Langhill (1999), for example, ‘indigenous knowledge’ is said to refer to the knowledge possessed by the original inhabitants of an area, while the term ‘local knowledge’ refers to the knowledge of any people, not necessarily indigenous, who have lived in an area for a long period of time. After considering all these terms, the term indigenous knowledge is adopted in this research. According to Mugabe *et al*. (2010), the local weather and climate is assessed, predicted and interpreted by locally observed variables and experiences using combinations of plants, animals, insects and meteorological and astronomical indications.

Wireless sensor networks

A wireless sensor network (WSN) is a collection of relatively small, self-contained, micro-electro-mechanical devices. These tiny devices have sensors, computational processing ability, wireless receivers with transmitter technology and a power supply (Eiko and Bacon 2005). Figure 1 shows an example of a sensor board (agricultural sensor board by Libelium; http://www.libelium.com/) capable of sensing temperature, relative humidity, atmospheric pressure, soil moisture, soil temperature and solar radiation among others

Wireless sensor network-based applications have been successfully deployed for weather forecasting and prediction, health-care monitoring, habitat monitoring, precision agriculture and tsunami warning systems, among others. They can be used to accurately predict droughts and reduce their impact by providing timely, relevant and accurate drought alerts. They are recommended for use in Africa because they have desirable features such as: (1) limited power requirements that can be easily harvested (e.g. solar power) or stored (e.g. batteries); (2) ability to withstand communication failures; and (3) large scale of deployment.

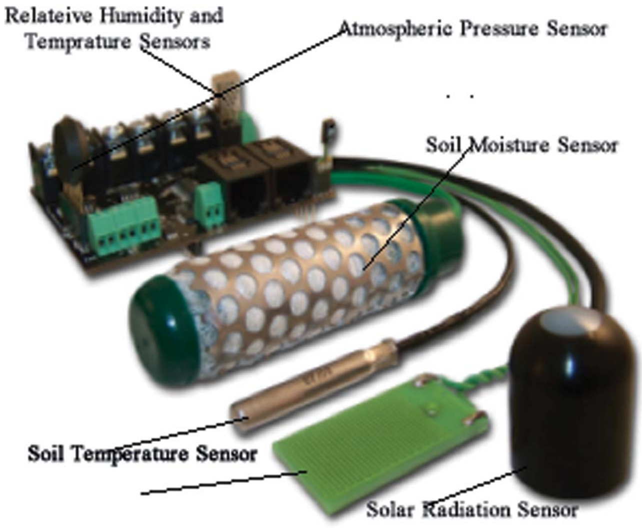


Figure 1. Agricultural sensor board.

Indigenous knowledge and ICTs

Researchers today concur that IK and modern science complement each other. In Dondeyne *et al*. (2003), for example, bridging local farmers' and scientists' knowledge through participatory research led to more appropriate technologies. It was a win–win arrangement where both parties learned from each other. So, do the modern approaches to drought prediction complement or contradict the African IK? First, the accumulated IK has always worked for the locals; the debate here can only be on the level of success. On the other hand, Western approaches to weather prediction hardly work for the mostly illiterate farmers, most of whom live in remote villages where modern technologies such as televisions and the internet are still a foreign concept. Second, implementing modern drought prediction technologies is still a costly affair for most African countries, whose priority list is filled with items such as 'providing basic education', 'implementing a democratic constitution', 'peace initiatives', 'providing basic healthcare' and so on. Installing a single modern weather station costs tens of thousands of euros. Moreover, qualified meteorologists are expensive to train and, after all this, the disseminated weather information is not usable by the farmers. In contrast, IK is cheap and time-saving and no formal training is required. However, having said this, the various effects of events such as colonialism, Western education systems, globalization, the ICT revolution and global warming make it impossible to talk about IK in isolation. Most of the IK on droughts and indeed other domains has been eroded over the years; the younger, urbanized, educated generation does not know much about IK. Online databases can certainly be used to conserve the little that is left.

It is indisputable that ICTs can be used to significantly improve drought prediction. The ITU (2008) has acknowledged the critical role of ICTs, especially in addressing food insecurity (mostly a consequence of droughts), and suggests that ICTs can be used: (1) to provide remote sensing infrastructure (such as WSNs); (2) as equipment (software and hardware) for analysis of drought data, including statistics, modelling and mapping (e.g. personal digital assistants, laptops, servers, databases, GIS, data mining and neural networks); and (3) as communication infrastructure to disseminate the relevant information to farmers and consumers (e.g. internet and cell phones). One of the ICT areas with the highest potential is WSNs.

Weather monitoring is one of the main drought mitigation strategies. In most countries in Africa, this is currently implemented using macro-infrastructures based on expensive and well-calibrated weather stations. The stations are then sparsely deployed by governmental organizations in the form of a relatively small number of fixed locations to provide climate maps for prediction of droughts and other natural disasters. This creates a feasibility gap that needs to be addressed through complementary technologies, systems and strategies. The emerging WSN technology has the potential to bridge this gap. This technology provides support for low-cost weather stations, which can be used by academics and the civil society to build community sensor networking micro-infrastructure based on off-the-shelf sensing devices. These can then be deployed in the environment to extend the available climate maps and prediction through the collection of climate data and pre-processing of this data. This is because these relatively cheaper (than conventional weather stations) WSNs can be deployed in large numbers in order to accurately measure meteorological parameters such as temperature, wind speed/direction, soil moisture, precipitation, atmospheric pressure, relative humidity and cloud cover. These readings can then be used, together with other less obvious aspects of IK (such as observed behaviour of animals/birds/plants and religious beliefs) to improve predictions.

Although still experiencing a mobile phone penetration lag[1] of close to 10 years, Africa has achieved an average penetration level of 41% (ITU 2010), which is much higher than that of computers. For instance, according to Kenya's 2009 population sensors (KNBS 2009), only 3.6% of households owned at least one computer in comparison with 63.2% of households that owned at least one mobile phone. With well-designed solutions, the use of these phones can be extended from the traditional use (as just communication devices) to being computing devices on which weather forecasting applications can be executed, for example, grid and service-oriented computing (Masinde *et al*. 2010, 2012). In this context, the phone plays the role of the 'last mile', disseminating weather and droughts alerts instead of the now threatened traditional means of using drums and horns. In this way, ICTs complement (and not contradict) IK.

Indigenous knowledge and agents

A recent study (Ziervogel and Opere 2010) one of whose main objectives was to establish the extent to which agricultural and pastoral communities in Sub-Saharan Africa made use of weather forecasts provided by national weather departments, confirmed two long-standing facts:

(1) The SCFs provided by the various national meteorological bodies are difficult to interpret and respond to; the local communities hardly make use of them.
(2) These communities continue to rely on IKFs.

In Ziervogel and Opere's research one of the projects was a three-year initiative entitled 'Integrating indigenous knowledge in climate risk management to support community based adaptation in western Kenya'. In this project meteorologists and the Nganyi indigenous knowledge forecasters worked together in building 'reconciliations' between SCFs and IKFs. Although this resulted in enhanced utlization of the weather forecasts, the project still faced two challenges:

(1) Lack of adequate localized meteorological data owing to the sparse nature of the available weather stations. Deploying the cheaper WSNs in large numbers to collect micro weather data can easily address this challenge.
(2) Lack of automated ways of porting the solution from one locality to another. This is partly due to the fact that some aspects of IKFs are based on myths that may not have relevance across communities. This is further compounded by the fact that those aspects that are common (most biophysical indicators such as the position of the sun/moon/stars, the behaviour of birds/animals and tree flower/leaf patterns) across communities are not systematically documented to allow for automation. Well-designed system software that makes use of intelligent agents and the now prevalent mobile phones can be used to address this challenge.

The comparisons between the SCFs and IKFs in Table 1 give an insight into the intricate nature of the synergies between the two. Most of the aspects of IKFs as described in Table 1 make it difficult to represent the knowledge in today's computer data structures. Yet, for effective drought prediction purposes, this needs to be combined with the more formal SCFs. This definitely calls for some level of reasoning, autonomy and distribution; agent technology is one way of achieving this. Agents have been known to perform well in conquering system complexity as well as in autonomous mission-critical systems. The greatest strength of agents is their ability to be autonomous; this is supported by the following agent capabilities (O'Hare and Jennings 1996): (1) perception and interpretation of

Table 1. Comparisons between indigenous knowledge-based seasonal forecasts and seasonal climate forecasts (adopted from Ziervogel and Opere 2010).

Indigenous knowledge-based seasonal forecasts	Seasonal climate forecasts
Use biophysical indicators of the environment as well as spiritual methods	Use of weather and climate models of measurable meteorological data
Forecast methods are seldom documented	Forecast methods are more developed and documented
Up-scaling and down-scaling are usually complex	Up-scaling and down-scaling are relatively simple
Application of forecast output is less developed	Application of forecast output is more developed
Communication is usually oral	Communication is usually written
Explanation is based on spiritual and social values	Explanation is theoretical
Taught by observation and experience	Taught through lectures and readings

incoming messages and data; (2) reasoning upon their beliefs; (3) decision-making (goal selection, solving goal interactions, reasoning on intentions); (4) planning (selection or construction of action plans, conflict resolution and resource allocation); and (5) ability to execute plans, including message passing.

Agents are classified based on various degrees of problem-solving capabilities. The two main categories are: *reactive agents*, which are able to react to changes in the environment or messages from other agents; and *intentional agents*, which are able to reason on their intentions and beliefs and to create plans and actions and execute those plans. *BDI agents* are a category that was established in the 1980s resulting from studies aimed at comparing agents with psychological studies of the mind and humans. They refer to systems whose behaviour can be described by attributing to the system mental attitudes such as ‘belief’, ‘preference’ and ‘intention’. These attitudes are further classified into: (1) *cognitive* – epistemic issues such as belief and knowledge; (2) *conative* – issues related to action and control such as intention, commitment and plan; and (3) *affective* – issues related to motivations such as desires, goals and preference. From these, *belief*, *desire* and *intention* were used to represent each of these categories; hence the name BDI agents. *Belief* is used to represent what the agent holds about the environment and about itself; this is in no way related to the beliefs as defined in the IK domain. On the other hand, *desire* and *intention* represent the state of affairs that the agent wishes to bring about. Intentions differ from desires in that intentions measure the commitment that leads to and controls the future actions of the agent; an agent may have desires but never set out to fulfil them (Agent Oriented Software Pty Ltd 2011).

As shown in Figure 2, the main components of BDI are:

1. a database of beliefs consisting of world facts as well as data relevant to the agent’s internal state;
2. a set of the agent’s goals or objectives (desires);
3. a set of plans necessary to achieve these goals; and
4. an ordered set of these plans (intentions).

Various BDI architectures have evolved over time, two of which are IRMA – Intelligent Resource-bound Machine Architecture – and the Procedural Reasoning System, PRS. PRS

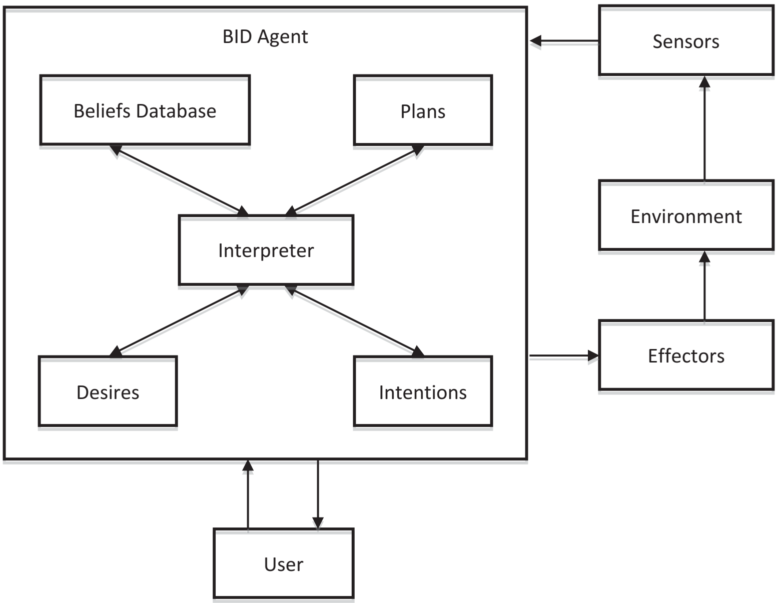


Figure 2. The BDI basic structure.

is simpler and has been implemented within the JACK Agent Development Environment. JACK (Agent Oriented Software Pty Ltd 2011) extends Java to support agent-oriented programming. It provides five main class-level constructs:

(1) agent – defines an intelligent software agent's behaviour such as the capabilities of the agent, types of messages, events it responds to, and plans it uses to achieve its goals;
(2) event – describes an occurrence to which the agent must respond;
(3) plan – the instructions that the agent follows in order to achieve its goals and handle its designated events;
(4) capability – includes plans, events and beliefs that give an agent certain abilities;
(5) belief set (database) – relational database representing agent beliefs.

Some success stories of JACK can found in Mehdi and Ghorbani (2004), where JACK was used to implement an intelligent system for detecting intrusion in a computer network, as well as in Randall and Gaudet (2008), where it was used to implement priority task management.

Proposed integration framework

Overview

This is work is part of a larger project (Masinde and Bagula 2010) whose main objective is to integrate mobile phones and wireless sensors in delivering a relevant and micro-drought prediction tool for the developing countries of Africa through augmenting indigenous knowledge on droughts. In the final solution, most of the computation will take place on mobile phones operating in grid architecture (Masinde *et al*. 2010). The rationale for using mobile phones as the main computation device is the fact that the penetration of

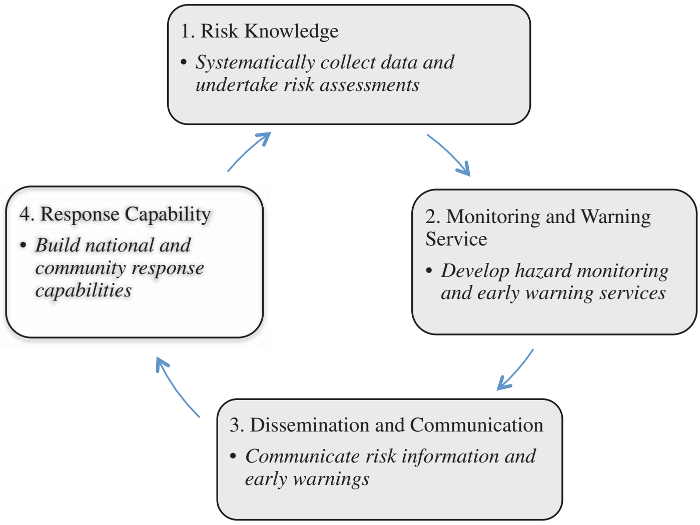


Figure 3. Four elements of people-centred early warning systems.

mobile phones in Africa is much higher than that of computers. Further, by utilizing an already existing computing platform (mobile phones), there is no need to invest in computers; this results in a cheaper drought prediction solution. The current project status is that sensors have been purchased, configured and installed at the Chiromo Weather Observatory at University of Nairobi, Kenya. A prototype mobile phone application for collecting IK has been developed using Android and a web-based database for storing the weather/agricultural values from the sensors has been designed and implemented on MYSQL/PHP. Below is a detailed description of the framework.

Indigenous knowledge within an early warning system for droughts

As described in ISDR (2006), a complete and effective early warning system is described as one that comprises four components:

(1) risk knowledge;
(2) monitoring and warning service;
(3) dissemination and communication; and
(4) response capability.

The first step is to harvest the immense IK lodged within the communities using the readily available mobile phones. As shown in Figure 4, the knowledge is then stored in a database from where it can be accessed for various uses, in this case to monitor and predict droughts. This generic design provides room for the framework to be ported across other IK domains such as indigenous medicine.

Framework design

Capture sensor data

Wireless sensors based on the Libelium (http://www.libelium.com/) agricultural board and e-weather stations installed in selected locations measure the following

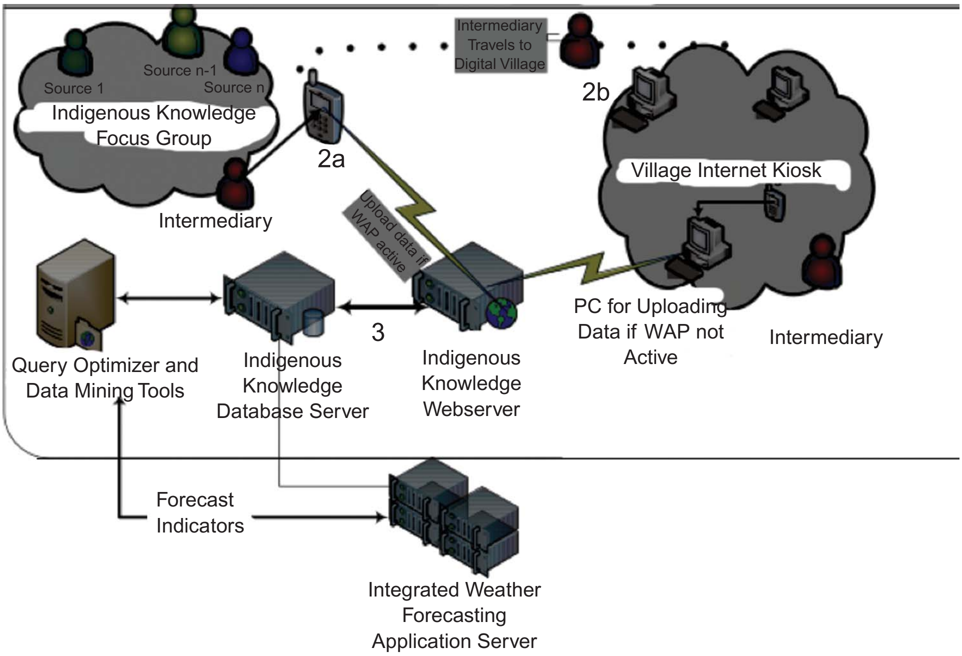


Figure 4. Framework for conserving IK on droughts.

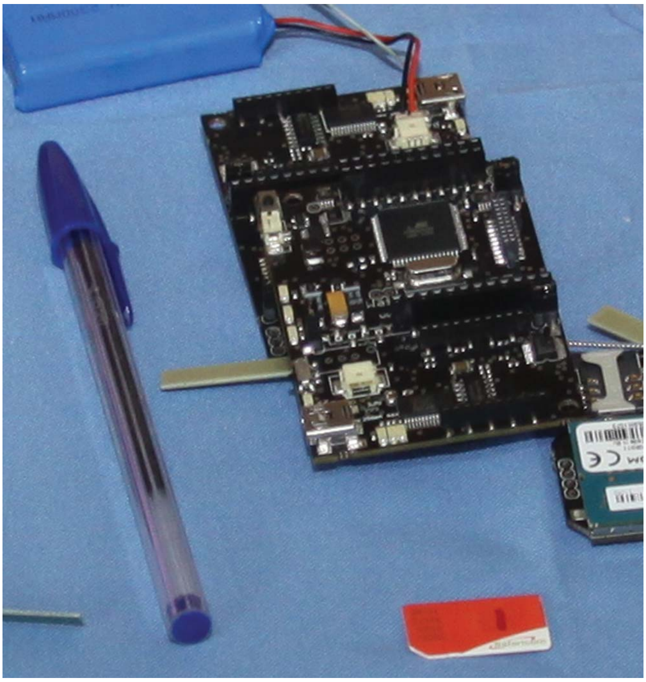


Figure 5. Actual size of the agricultural board.

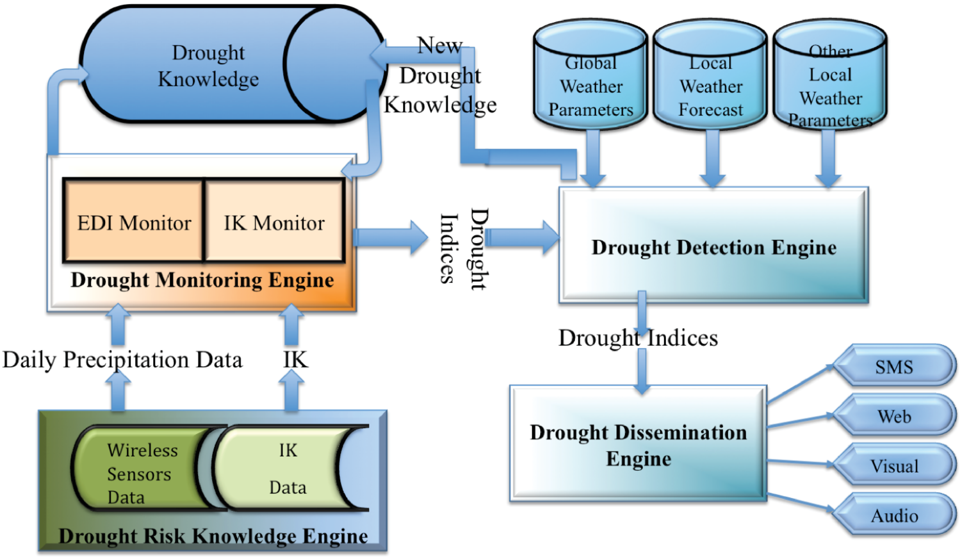


Figure 6. The proposed integration framework.

meteorological/agricultural parameters: temperature, relative humidity, atmospheric pressure, leaf wetness, soil temperature and soil moisture, precipitation, wind speed and wind direction. This sensor is small enough to fit in the hand, as shown in Figure 5. A major part of the sensor-board is a lithium battery (blue), which is used to power the sensor while in the field.

Currently, the sensors take readings every 30 min (except for rainfall, which is read only when rain drops are detected) and the values stored in a removable memory card. In parallel with this method, the sensors send hourly average readings (computed from the 30 min interval readings) to the server in the form of text messages (SMS). Data from the Secure Digital (SD) cards are manually uploaded to the server after every 12 h.

As depicted in the architecture (see Figure 6), the sensor readings are automatically transmitted in the form of text messages (GPRS/GSM) to the database at pre-determined intervals. Given that there is a cost associated with text messages, in future deployments, the transfer will be done via the cheaper Bluetooth and/or WiFi and ZigBeefore (Wikipedia 2010) over short distances.

Capturing IK

The current system prototype was developed to work with an already existing manual system that seeks to integrate indigenous weather forecasts by the Nganyi Clan in Kenya with the seasonal climate forecasts by the Kenya Meteorological Department (Ziervogel and Opere 2010). In this way, the IK for this Clan is already collected and stored in various formats. This was reformatted to fit our database format. However, in the final system, for each community targeted, an intermediary (who understands both English and the local language as well as ICT and meteorological terms) will be identified and used as the interface to the community. Using a mobile smart phone application (see Figure 7), the intermediary will key in all the IK provided by the identified respondents. Once the information is stored on the phone, it will then be sent to the database via the phone's WAP facility. Where the

Figure 7. Mobile phone application prototype.

WAP facility is not available, the intermediary has the option of visiting the nearest internet kiosk (http://www.elearning-africa.com/eLA_Newsportal/rural-internet-kiosks-herald-last-frontier-in-bridging-digital-divide/) from where he/she can access the database and upload the collected information.

Drought prediction algorithm implementation

Once both the sensor data and IK are stored, universal data representation structures, XML and RSS, are employed to interface the data with a set of BDI agents implemented using the JACK agent development environment. The system has been implemented using five BDI agents:

(1) *IK agents* – for storing and manipulating indigenous knowledge.
(2) *Local weather agents* – to represent observable weather attributes that are not captured by the sensors, e.g. cloud cover and weather conditions (thunderstorms).
(3) *EDI agents* – to compute the effective drought index. There are several well-developed indices for quantifying the effects of droughts in terms of parameters such as intensity, duration, severity and spatial extent. These indices map the droughts to different time scales (daily, weekly, monthly, annually, etc.) and geographical regions to aid the planning and decision-making process. Byun and Wilhite (Wilhite and Glantz 1985) developed the effective drought index (EDI) to address weaknesses that they identified in the existing (at the time of their research) drought indices. Some of the desirable features of the EDI are that (a) it calculates daily drought severity, (b) it more accurately calculates the current level of

available water resources, (c) it considers drought continuity, not just for a limited period, and therefore it can diagnose prolonged droughts that continue for several years, (d) it is computed using precipitation alone, and (e) it considers daily water accumulation with a weighting function for time passage. Calculation is therefore made with consideration for the fact that the quantity of rainfall that can be used as a water resource drops gradually over time after the rain has fallen. It is based on these strengths that EDI was chosen for this research.

(4) *Global weather agents* – given that the weather of a given place is affected by global weather trends, these agents will be used to monitor and provide various (and relevant) weather parameters for use in the drought prediction

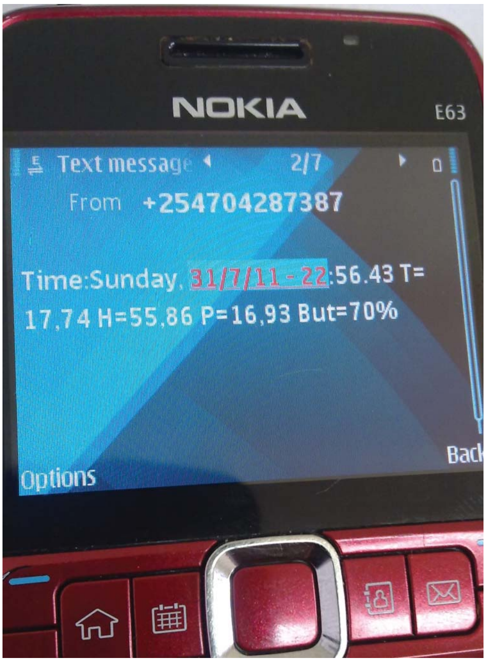
(5) *User interface agents* are responsible for presenting the prediction results in forms and formats that are appropriate to all the stakeholders.

Implementation and testing

The integration framework system prototype was implemented as a set of four sub-systems called ‘engines’.

Drought risk knowledge engine

Data used for IKFs is collected using mobile phone applications, while that for SCFs is read directly from the wireless sensors. Figure 8 shows an example of a message sent from a sensor; it gives the temperature, atmospheric pressure and relative humidity readings for 31 July 2011 at 22:56. For equipment monitoring purposes, the readings also include the percentage (70%) of battery power left. Both the data from the sensors and that from



From +254704287387

Time:Sunday, 31/7/11 - 22:56.43 T= 17,74 H=55,86 P=16,93 But=70%

Figure 8. Sample SMS sent from a sensor-board.

the mobile phone application are stored in MYSQL database for further processing using intelligent agents.

Drought monitoring engine

This is responsible for analysis the data from the drought risk knowledge engine. This task is implemented in form of two categories of agents: EDI monitoring agents and IK monitor agents. EDI monitoring agents compute the daily effective drought index. The agents are implemented as a set of plans that use daily precipitation height values and effective precipitation (EP^2) to compute the deficiency or surplus of water resources for a particular date and place. The output is in the form of real values (positive or negative) that represent the available water deficit (−ve) or excess (+ve). EP makes use of the following equation:

$$EP_i = \sum_{n=1}^{i} \left[\left(\sum_{m=1}^{n} P_m \right) / n \right]$$

EDI is a relative value and the interpretation of the result is determined by a number of factorsm such as the climate of the location, the season (rainy or dry), the previous day's value and cumulative weekly/monthly/season/annual value. The agent has to intelligently 'reason' before classifying the value under the one of the following classifications:

- extreme flood – $EDI > 2$;
- severe flood – $1.5 > EDI < 1.99$;
- moderate flood – $1 > EDI < 1.49$;
- wet, near normal – $0.01 < EDI > 0.99$;
- drought, near normal – $-0.99 < EDI > 0.00$;
- moderate drought – $-1 < EDI > -1.49$;
- severe drought – $-1.5 < EDI > -1.99$;
- extreme drought – $EDI < -2$.

The above was adapted from Wilhite and Glantz (1985) to suit the rainy seasons experienced in most countries in Africa. IK monitoring agents on the other hand interpret and make logical interpretations of the complex indigenous knowledge. Logical members – a new (to Java) data structure introduced in JACK – are used to store the IK.

Drought detection engine

The drought/climatic variation of a given location is highly influenced by conditions external to the location; the drought detection engine takes care of this aspect. It takes as input the drought indices from the drought monitoring engine and intelligently analyses them in relation to global weather patterns, the weather forecast for the location under consideration and local weather parameters (temperature, wind speed/direction, atmospheric pressure, soil moisture and relative humidity). The latter is important because our drought monitor engine (EDI agents) only considers precipitation when computing the effective drought index. It is here that the comparisons between the prediction SCFs and IKFs are made and an acceptable verdict reached through various adjustments/compromises of either or both forecasts/predictions. This process involves human (meteorologists and community 'rain-makers') intervention to make various interpretations, but will in future be fully automated using various artificial intelligence techniques.

Drought dissemination engine

This is responsible for customizing the syntax and semantics of the drought alerts to suit the diverse audience. These are the most complex agents in our system, handling:

(1) Natural language translation aimed at supporting African local languages. This is to serve African farmers, most of whom are illiterate/semi-illiterate.
(2) Text-to-speech translation so that alerts can be read out to users who cannot read.
(3) Conversion of input to visual displays for viewing on billboards.
(4) Display of graphs and text on web pages.

Currently, our prototype supports only two of these agents' roles: web portal and natural language (English) interface to database.

Conclusion

In this paper, we have described ongoing research work that entails developing a framework for integrating on the one hand indigenous knowledge on droughts vs wireless sensor networks and, on the other, mobile phones. We have also described a system prototype that implements this framework. In order to test the system prototype in a real-world environment, this system has been incorporated within a predecessor project that is aimed at creating harmonization between the SCFs by the Kenya Meteorological Department and the indigenous weather forecasts by the Nganyi Clan. The prototype's performance is due for evaluation at the end of the next (January 2012) rain season, which is expected to start in October.

Although still at the prototype stage, our drought early warning system that has been built using agents offers a unique and promising solution to drought prediction, an area where very few systems exist. Drought prediction is so complex that most existing solutions give dismal performance, especially in terms of quantifying droughts. Our solution creates autonomous agents for handling all the complex variables that are used in computing drought indices. The use of indigenous knowledge weather forecasting indicators, which are integrated with weather data read from wireless sensors and other external (to a given location) parameters, is a novel contribution. Further, through the dissemination agents, our solution provides 'localized' (meaningful) drought alerts to stakeholders, especially illiterate and semi-illiterate farmers in the rural areas of Africa. Moreover, the use of cheaper (than professional weather stations) mobile phones for drought data (the indigenous knowledge) collection and for drought dissemination makes the solution more sustainable and affordable for African countries. By using already existing (mobile phones) platforms, little extra investment is needed and it is therefore a cheaper solution. Finally, the adoption of the effective drought index in our system makes it possible to quantify and qualify droughts in absolute terms (Masinde and Bagula 2011) as to their start/termination and severity. The design of our system is generic and can therefore be customized for other kinds of early warning systems. In particular, our system requires minimal modification to be able to act as a climate change early warning system.

Notes

1. The time gap between mobile phone penetration level in Africa, and the year that the same level of penetration was achieved globally.
2. The EP is the summed value of daily precipitation with a time-dependent reduction function.

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Antoine Bagula received an MEng degree in Computer Engineering from the Catholic University of Louvain in Belgium and an MSc Degree in computer science from the University of Stellenbosch in South Africa. He obtained a PhD in communication systems from the KTH-Royal Institute of Technology in Sweden. The focus of his research is the design, analysis and control of intelligent telecommunication systems and their integration into the emerging ubiquitous networks. His current interests include the modelling, optimization, performance evaluation and implementation of RFID and radar networks, sensor/actuator networks as well as next-generation IP/optical networks. Besides his strong involvement in research at the academic and industry levels, Dr Bagula is currently involved in training activities in developing countries as an ICTP, ISOC and wireless trainer/consultant. At the University of Cape Town, Dr Bagula leads the Intelligent Systems and Advanced Telecommunication Laboratory of the Department of Computer Science. He is also an active member of the ICT4D centre.

References

Agent Oriented Software Pty Ltd, 2011. *JACK: Jack intelligent agent user guide*.

Ajibade, L.T. and Shokemi, O., 2003. Indigenous approach to weather forecasting in ASA L.G.A., Kwara State, Nigeria. *African Journal of Indigenous Knowledge Systems*, 2 (1), 37–44.

Dondeyne, S., Emanuel, L.B., and Deckers, J.A., 2003. Mr Napite's botanical knowledge: bridging farmers' and scientists' insights during participatory research. *African Journal of Indigenous Knowledge Systems*, 2 (2), 45–57.

Eiko, Y. and Bacon, J., 2006. *A survey of wireless sensor network technologies: research trends and middleware's role*. University of Cambridge Technical Report.

Huschke, R.E., 1959. *Glossary of meteorology*. Boston, MA: American Meteorological Society.

ISDR, 2006. Developing early warning systems: a checklist. *In*: *Third international conference on early warning: from concept to action, EWC III*, pp. 1–13.

ISDR, 2008. *3rd African drought adaptation forum report*, Addis Ababa, Ethiopia, 17–19 September 2008. ITU, 2008. *Ubiquitous sensor networks (USNs)*. ITU-T's Technology Watch Briefing Report series, No. 4 (February). Available from: www.itu.int/dms_pub/itu-t/oth/23/T23010000040001PDFE.pdf.

ITU, 2010. *The world in 2010 ICT figures: the rise of 3G*. ITU-D, ITU World Telecommunication/ICT Indicators database.

Johnson, M., 1992. *Lore: capturing traditional environmental knowledge*. Ottawa: Dene Cultural Institute and the International Development Research Centre.

KNBS, 2009. *The Kenya census 2009: population and housing census highlights*. Nairobi: Government Press.

Langhill, S., 1999. *Indigenous knowledge: a resource kit for sustainable development researchers in dryland Africa*. Ottawa: IDRC.

Loubser, J.A., 2005. Unpacking the expression 'indigenous knowledge systems'. *African Journal of Indigenous Knowledge Systems*, 4 (1), 74–86.

Masinde, M. and Bagula, A., 2010. A framework for predicting droughts in developing countries using sensor networks and mobile phones. In: *Proceedings of SAICSIT 2010*, Bela Bela, South Africa. New York: ACM, 390-393. Available from: http://dl.acm.org/citation.cfm?id=1899551&dl=ACM&coll=DL&CFID=78821470&CFTOKEN=21038012

Masinde, M. and Bagula, A., 2011. The role of ICTs in quantifying the severity and duration of climatic variations – Kenya's case. *ITU Kaleidoscope*, 12–14 December.

Masinde, M., Bagula, A., and Murage, V., 2010. MOBIGRID: a middleware for integrating mobile phone and grid computing. *In*: *The 6th international conference on network and service management, CNSM 2010*, 25–29 October. New York: IEEE Communications Society.

Masinde, M., Zeba N., and Bagula, A., 2012. Extending the power of mobile phone using service oriented computing. *In*: N. Venkatasubramanian *et al*., eds. *Mobilware 2011, LNICST 93*. Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, 34–44.

Mehdi, S. and Ghorbani, AA., 2004. Application of belief–desire–intention agents in intrusion detection and response. *PST*, 13–15 October. 181–191.

Mishra, A.K. and Desai, V.R., 2006. Drought forecasting using fee-forward recursive neural network. *Ecological Modeling*, 198, 128–138.

Mugabe, F.T., *et al*., 2010. Use of indigenous knowledge systems and scientific methods for climate forecasting in southern Zambia and north western Zimbabwe. *Zimbabwe Journal of Technological Sciences*, 1 (1).

Njiraine, D., Ocholla, D.N., and Bosire, O.O., 2010. Indigenous knowledge research in Kenya and South Africa: an informetric study. *African Journal of Indigenous Knowledge Systems*, 9(2), 194–208.

O'Hare, G.M.P. and Jennings, N.R., 1996. *Foundations of distributed artificial intelligence*. New York: John Wiley & Sons.

Panu, U.S. and Sharma, T.C., 2002. Challenges in drought research: some perspectives and future directions. *Hydrological Sciences Journal* 47 (August), 19–30.

Red Cross, 2010. *The International Federation of Red Cross and Red Crescent Societies*. World Disaster report 2010 – Focus on Urban Risk [online]. Available from: http://www.ifrc.org/Global/Publications/disasters/WDR/WDR2010-full.pdf

Roos, V., Shingairai, C., and Niekerk, D.V., 2010. Coping with drought: indigenous knowledge application in rural South Africa. *African Journal of Indigenous Knowledge Systems*, 9 (1), 1–10.

Rosenberg, N.J., 1979. Drought in the Great Plains – research on impacts and strategies. *In*: *Workshop on research in Great Plains drought management strategies*, 26–28 March. Highlands Ranch, CO: Water Resources Publications.

Steiner, A., 2008. *Indigenous knowledge in disaster management in Africa*. United Nations Environment Programme (UNEP). Available from: http://www.unep.org/IK/PDF/IndigenousBooklet.pdf

Szöllösi-Nagy, A., 1999. *Integrated drought management: lessons for Sub-Saharan Africa*. International Hydrological Programme, UNESCO Division of Water Sciences. Available from: http://www.unesdoc.unesco.org/images/0012/001262/126257e.pdf

Randall, T.E. and Gaudet, B.J., 2008. Implementing priority task management in Jack intelligent agents. *SpringSim '08*, 14–17 April. *In: Proceedings of the 2008 Spring simulation multiconference.* San Diego, CA: Society for Computer Simulation International article 14.

UNEP, 2011. *Indigenous knowledge home* [online]. Available from: http://Hqweb.Unep.Org/Ik/ [Accessed 3 May 2011].

Warwick, R.A., 1975. *Drought hazard in the United States: a research assessment*. Nsf/Ra/E-75/004. Boulder, CO: University of Colorado, Institute of Behavioral Science.

Wikipedia, 2010. *Zigbee* [online]. Available from: http://en.wikipedia.org/wiki/ZigBee [Accessed 3 May 2011].

Wilhite, D.A. and Glantz, M.H., 1985. Understanding the drought phenomenon: the role of definitions. *Water International*, 10 (3), 111–120.

Yevjevich, V., Hall, W.A., and Salas, J.D., 1977. Drought research needs. *Conference on drought research needs*, 12–15 December, Colorado State University, Fort Collins, CO.

Ziervogel, G. and Opere, A., 2010. *Integrating meteorological and indigenous knowledge-based seasonal climate forecasts for the agricultural sector: lessons from participatory action research in sub-Saharan Africa*. IDRC [online]. Available from: http://web.idrc.ca/uploads/user-S/12882908321CCAA_seasonal_forecasting.pdf