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Network Densification Strategies for Automatic Weather Stations: Challenges and Opportunities for Uganda

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Abstract: Access to quality, accurate and timely weather information is important. In order to improve weather information quality and quantity, increasing the number of operational Automatic Weather Stations, also referred to in this document as densification should be prioritized. In this paper, we provide research findings of a survey conducted from November 2014 to January 2015 to ascertain the status of weather stations in Uganda. Weather station density was found to be sparse and yet many of the available weather stations were non-functional. Based on the distribution of available operational weather stations, we are proposing densification strategies including climatological zones, security and land policies. To achieve sustainability of the weather stations, we commend improving human resources aspects among other things

Keywords: Densification, Automatic Weather Station, Climatological zones, Weather Station density

1. Introduction

In Uganda, about 70% of citizens rely on subsistence farming, which is heavily dependent on rain seasons [1]. The Uganda Bureau of Statistics presented a report of a survey in which the status of employment showed a fraction of 71.9% of the population in Uganda relying on agriculture, forestry and fishing [2]. Many other sectors rely on weather information and as such it is important that weather information delivery be done accurately and in a timely manner. The Uganda National Meteorological Authority (UNMA) is the government authority charged with the management of weather stations in the country performing duties like installing new weather stations, maintaining them, collecting and processing weather data and disseminating the generated information among others.

Weather stations may typically be classified into two broad categories. The first is manual Stations, in which the environmental data from meteorological instruments is observed, recorded and reported by human observers. The other category is Automatic Weather Stations (AWS) which are electronic instruments that measure environmental data through sensors and record it, usually for later transmission to a central repository.

The number of AWSs in the country is still small and as such prediction models based on a variety of possible weather trends produce ambiguous results and less-predictable weather patterns [3]. Recent weather and climate changes have negatively impacted agriculture [4]. Farmers are experiencing increased temperatures, rain, and drought resulting into increased pests and disease, erosion, reduced crop yield and wild fires among others. Accurate weather prediction is important in adapting to the adverse conditions. However, the weather data collection methods used are inefficient resulting into inaccurate predictions. Also, the number of weather stations is not representative of big areas [5].

In order to increase the density of the weather stations in the country, other institutions besides UNMA installed their own weather stations. It is UNMA's role to ensure that all weather stations including the privately owned ones maintain the World Meteorological Organization standards.

WIMEA-ICT[1], a NORHED[2] project, being implemented by four academic institutions namely Makerere University (MAK), Dar es Salaam Institute of Technology (DIT), University of Bergen (UiB) and the University of Juba (UoB), in collaboration with their respective National Meteorological services, is aiming to improve weather information management through the use of suitable ICTs. The project intends to set up seventy (70) (AWSs) in the three partner African countries. Of the 70 AWSs, Uganda and Tanzania shall each receive 30 while South Sudan shall receive 10. At the time of the survey, which we conducted from December 2014 to January 2015 on the status of weather stations, Uganda had 37 weather stations. The project shall therefore contribute a percentage of 44.7% of the total number of weather stations.

While UNMA has the mandate to densify the network of AWSs in Uganda, one of the expected outcomes of the WIMEA-ICT project is to assist UNMA achieve that goal. To this end, strategies of choosing the locations of new Automatic Weather Stations with the aim of acquiring a representative network are our focus.

The rest of the paper is organized as follows: We present our survey findings in section 2. In section 3, we discuss how WIMEA-ICT leverages ICT, in section 4, we discuss the densification strategies and propose locations for the new weather stations in section 5 and lastly present our recommendations and conclusion in section 6 and 7.

2. Findings

Among the 14 weather stations we visited, 2 were manual, 2 had only automatic weather stations while 10 had both automatic and manual weather stations in the same place. Most of the automatic weather stations were not fully functional due to reasons given in Table 1.

Table 1 Challenges of Automatic Weather Stations

Challenge	**No of stations**
Faulty components	9
Communication problems	6
Poor staffing	12
Vandalized	3
Power Problems	3

Staffing challenges include both small number of employees and limited technical knowledge of weather station observers on how to troubleshoot and maintain weather stations.

UNMA and NARO provided a list of 37 weather stations represented in Figure 1. We managed to visit 14 of those. The weather stations are placed in 14 climatological zones, one of our main densification strategies which we later discuss in detail. The climatological

[1] A project that seeks to Improving Weather Information Management in East Africa for effective service provision through the application of suitable ICTs
[2] A Norwegian Programme for Capacity Development in Higher Education and Research for Development

zones were established using principal component analysis of rainfall patterns over the whole country [6]. All climatological zones have weather stations. However, the number of weather stations is still small.

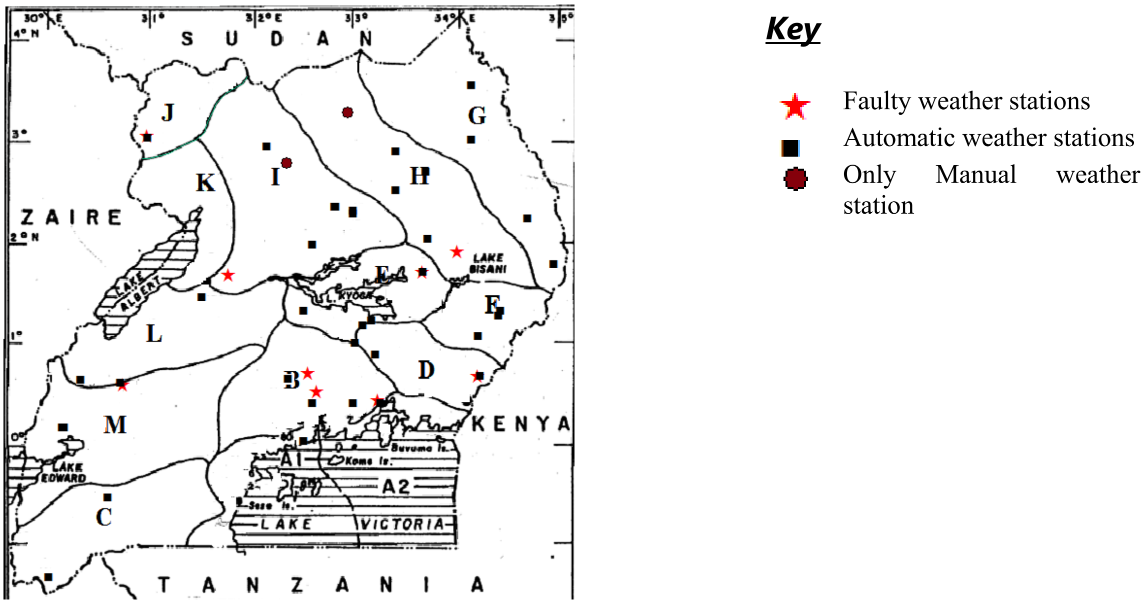

Figure 1 Distribution of Weather Stations provided by UNMA an NARO

3. Leveraging ICTs in Automatic Weather Stations

3.1 Use case of how An AWS operates

Figure 2 shows current communications pathway of a typical AWS. The weather stations distributed across the country periodically collect weather data and store it in the data logger, which is usually located at or near the weather station. After a period between one to three hours, the data logger sends the data to an observation station manually or automatically using either GSM/GPRS, Wi-Fi or Ethernet connections for Internet access. At the observation station, the data is aggregated from all the weather stations in the country to be fed into forecast models.

Transmitting data to the observation stations is subject to quality and strength of a network signal.

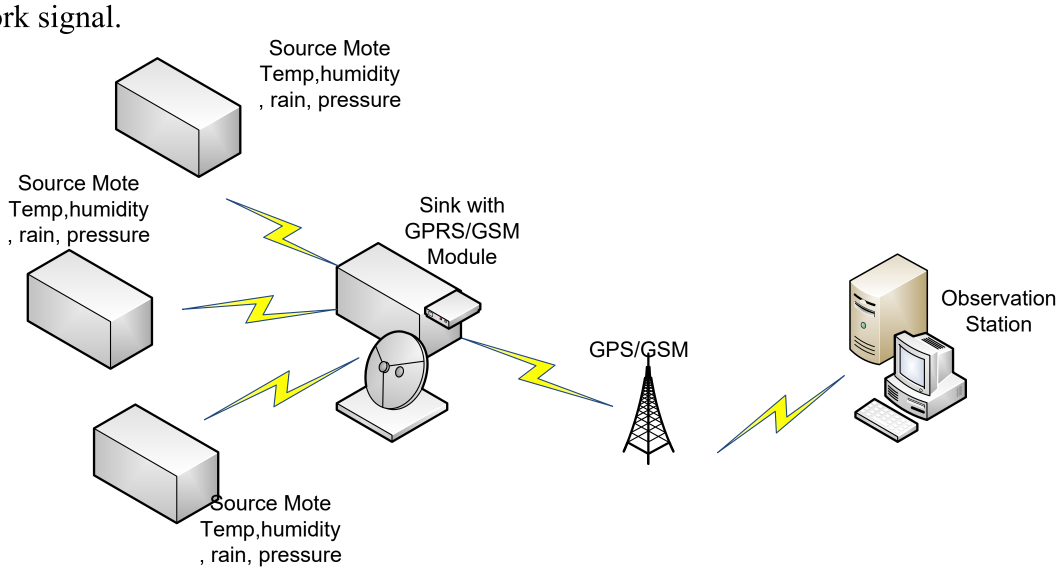

Figure 2 Communication Pathway for the weather station

3.2 Data Processing

The AWSs transmit their data to repositories, which shall be maintained by UNMA. The repository may contain legacy data which is imported from different weather stations. Once at the repository, modelling using tools like COSMO[11] and WRF[12] is performed on the data for prediction purposes. Weather prediction information is then accessed via websites, mobile phones, TVs and other traditional methods. The predictions may be customized in form of farming advisories such as when to plant or harvest or which crops to plant in a given season.

3.3 Cooperation among Uganda, Tanzania, University of Bergen and South Sudan

WIMEA-ICT project partners include MAK, Uganda, DIT, Tanzania, UoJ, South Sudan and UoB, Norway, Makerere University taking the lead. The National met services of the three African countries are project beneficiaries. Their role is to ensure that WIMEA-ICT products comply with the World Meteorological Organization (WMO) standards. The project's main objective is to improve Research and teaching capacity Building in the partner Universities and specifically improving Weather and Information management through suitable ICTs. Project activities include Undergraduate and Postgraduate curriculum development, supporting training of staff from the three African countries and participating in community programmes related to weather and climate. Research areas include numerical weather prediction, efficient power systems design and weather data communication among others. All partners have equal responsibility in the project. Research outputs expected from the project include AWSs designed and deployed in the three African countries, improved numerical prediction model, weather repository set up and models for customized weather information dissemination.

4. Densification

4.1 AWS Implementation and Operationalization

The automatic weather stations to be implemented shall be developed in three phases, each phase leading to a refined prototype. The first phase is already complete and a first generation prototype exists. Data from this prototype is available here [7]. A typical AWS will consist of wireless sensor nodes, each powered by solar energy, transmitting environmental data to a gateway device that will upload the data to a centralized server via one of the several communication pathways that will be used. This gateway is a Raspberry Pi connected to an uplink device. The applications running on the sensor nodes and gateway are developed using free and open-source technologies such as the GNU Compiler toolchain and the Linux operating system. For each prototype, there will be rigorous testing to benchmark the stations against other industry-standard devices. Operationalization will involve working with local manufacturers to produce the housing frames and to carry out civil works in the selected areas where the stations will be deployed. The selection criteria is discussed in section 4.2.

A typical use case of an AWS is at Makerere University where UNMA has deployed an industrial grade AWS that collects temperature, humidity, solar insolation, wind speed, wind direction and precipitation data. A major difference between this station and the one to be developed by the WIMEA-ICT project is that the former uses wired connections while the WIMEA-ICT AWS uses wireless connections.

A number of implementation problems are already foreseeable. The selection of the right solar panels to use so as to not attract vandals, the lack of several electronic components on the local market that have to be shipped in from Europe and China and several other challenges. We also believe the process of connecting the stations to the optic fibre backbone in Uganda and Tanzania will not be trivial, because of the magnitude of the civil works and state bureaucracy, even though the service provided through this channel may be very affordable.

Through the implementation and operationalization of these AWS, it is expected that a great deal of data will be collected in the areas of tele-connectivity, power consumption, sensor accuracy and general robustness.

4.2 Densification Strategies

We propose the following criteria for the selection of optimal locations to install the Automatic Weather Stations to be developed.

4.2.1 Climatological Zones

Uganda, being landlocked and filled with various geographical features such as mountains, lakes and vegetation demonstrates significant changes in climate per unit distance. For example, the areas that immediately surround Rwenzori Mountains in the South West of Uganda are more prone to rainfall even in the dry season. In the tropics, the climatic patterns of a region are adequately determined by the rainfall characteristics because rainfall is the climatic element which exhibits the highest variability both in time and space [6].

To this end, it appears that the large amounts of data to be collected from these stations provides for more accurate weather prediction results if analyzed basing on the climatological zones from which the stations are installed. The zones also are an indication of the spatial patterns of the physical features of Uganda. Our aim is to have weather stations in each of the climatological zones while adding more in bigger zones. In so doing, we shall ensure that there is representation of the climate across the country even with a limited number of weather stations.

4.2.2 Distribution of existing weather stations

One of the survey findings was that a few AWSs managed by UNMA are operational. This means that, data collected by these stations could be stored in the same repository as that from our new AWSs. To that end, any operational station in a climatological zone will be considered during the densification process.

The stations to be installed, therefore, should be at an optimal distance of separation from existing ones to avoid duplication, while, at the same time, promoting redundancy when either is down. While the number of existing weather stations is expected to grow as UNMA implements its mandate including the management of private weather stations not yet represented on the national weather station net. In spite of the expected distribution change, we only consider weather stations distribution at the time of study.

4.2.3 Network Coverage

Our major AWS communication criteria guideline is at least a 2G network coverage by at least one service provider to avoid restrictions on the locations of the stations to be installed.

During the assessment of mobile phone infrastructure, Uganda Communication Commission (UCC[3]) evaluated performance of telecommunication companies in terms of service maintenance, potential for market growth, service quality, prices, service penetration/coverage, costs and technology among other things [8]. While network

[3] The regulator of communications sector in Uganda

coverage has improved, service quality has remained a big challenge and is characterized by irregular outages caused by vandalism of equipment and fuel at cell sites. Although Internet speeds are low in urban centers, rural areas suffer more. The urban-rural digital divide is further being widened by limited infrastructure set up in the rural areas due to a perceived "lack of economic viability" for many Internet Service Providers. It was noted that service quality has been improving as towers are connected to the grid and security and enforcement is improved.

Suggestions to improve network connectivity include development of the dotUG management policy, which aims at harmonizing the management of the Policy Framework for management of .UG country code Top Level Domain (ccTLD)[9]. Within the policy, there is a requirement to put in place a not-for-profit organization to manage the dotUG resource. Government is also setting up a national backbone infrastructure (NBI). The NBI seeks to provide unlimited access to data connectivity and high speed internet at reduced cost to Government Departments and Agencies. A map of the regions so far covered by NBI is presented in [10]. Since the project intends to cover rural areas in which commercial companies have had less impact, connecting weather stations to such a network will greatly enhance communication of weather information in regions that will benefit from the network.

4.2.4 Security

While all the parameters discussed are fundamental to the deployment process of any AWS, we noted from our survey that security was an important parameter. To avoid vandalism, most stations were installed at the district or police headquarters. An example is Kamuli Met station which was installed at the district headquarters.

The general hypothesis regarding security is that there is more security nearer the town centers and municipalities rather than farther. One of the criteria to be used therefore is the installation of weather stations in the town centers.

UNMA is currently setting up partnerships with organizations such as schools to take over the maintenance of the weather stations. In that way, security of the weather stations will be guaranteed and vandalism lessened. Plans are also underway of setting up sensitization workshops for the people around the weather stations. It is important that the people are sensitized about the use of the weather stations and also consider taking up their maintenance where possible.

4.2.5 Land policies

When placing weather stations, land policies must be put into consideration. Most of the land is privately owned giving owners rights like selling, demolishing and constructing among others. If buildings are constructed next to weather stations, they interfere with parameters such as wind speed. Also, land owners may relocate weather stations.

Given this background, it is important that the selection of sites for placement of new weather stations be done based on ownership of the land by UNMA.

4.3 Impact

WIMEA-ICT project will benefit many sectors including agriculture, transport and construction, tourism and wildlife-related activities among others. AWSs operate 24/7 and in harsh environments unlike the manual weather stations, which require continuous human intervention. AWSs collect data in digital formats hence offering reliability, accuracy and timely delivery of data. Manual Weather Station data is prone to errors, which may be introduced during manual recording on paper, transmission or processing. Error free data produces accurate weather predictions, which help farmers in adapting to the changing environment and as such get better yields. In terms of costs, digital data is easy to analyse, cheap to transmit and operational costs are reduced since there is no need for observers.

5. Proposed Locations

We have used a combination of the above densification strategies to come up with locations for the new stations. While considering the operational weather stations in a selected climatological zone, town centers have been chosen for placement of the stations while putting in mind the number of weather stations in a climatological zone. Figure 3 shows proposed locations alongside the already existing weather stations. The proposed locations are triangular markers.

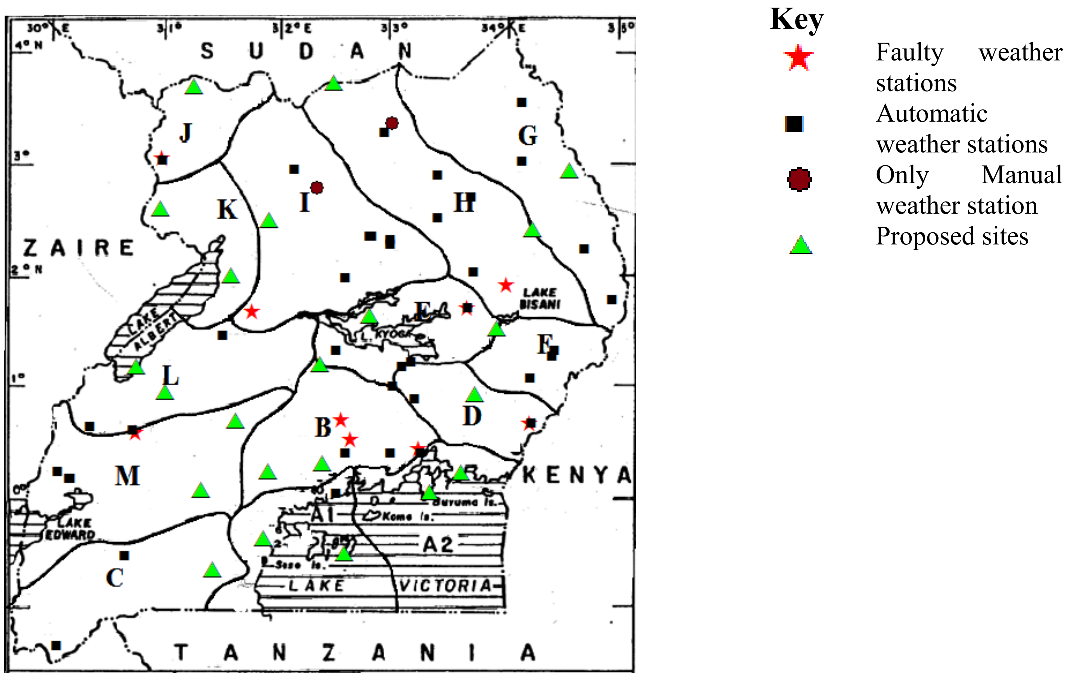

Figure 3 Proposed and existing weather stations

6. Recommendations

Whereas weather stations are in place, there is a need to improve their densification in order to have efficient and accurate weather forecasts. Moreover, cheaper and efficient means of disseminating these weather forecasts to the intended recipients needs to be explored. This calls for more automated weather stations with cheaper maintenance and lower initial costs. Discussions should also be stepped up between government and telecom companies for cheaper internet connections.

Despite the automation, we also recommend that a skeletal well trained staff be in place. The AWS should also be calibrated against the manual devices for easy comparison in the pilot stages.

7. Conclusion

Timely and accurate weather forecasts play a big role in almost all spheres of life, particularly within Agriculture for the case of East Africa. However, our survey findings show that there is a sparse weather station network in Uganda. We have recommended improvement on weather station densification, including a proposal for a low-cost automatic weather station (AWS). This AWS, which is being built in collaboration with all the partners (MAK, DIT, UoJ and UoB) is designed to be affordable and robust thus a potential benefit to the East African National Meteorological services towards efficient weather information management.

Acknowledgements

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