

Rainwatch

A Prototype GIS for Rainfall Monitoring in West Africa

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Based on the most comprehensive survey to date of seasonal climate forecast use in West Africa, conducted across four nations, Tarhule and Lamb concluded in a 2003 *BAMS* article that very few people in the Sahel use the results of climate research and few have access to seasonal forecasts, even though the vast majority seem willing to use such information. This mixture of discouraging yet optimistic findings differed little from the quarter-century-earlier assessment of Glantz (in a 1977 *BAMS* article), despite substantial opportunity and motivation for progress during the intervening time interval. That motivation was manifold: continuing rainfall deficits; growing understanding of the climate system causation, predictability, and societal impacts of Soudano-Sahelian drought and rainfall variation; strong evolution toward political and economic reforms; establishment and maturation of regional climate organizations; development of a seasonal forecast process; and ever-improving electronic communication technology.

To begin bridging this considerable gap between “what is” and “what ought to be,” borrowing Glantz’s (1977) terminology, Tarhule and Lamb (2003, Fig. 9) proposed a model for climate information flow in West Africa that went beyond what was previously envisioned (e.g., Regional Climate Outlook Forums Review Organizing Committee, RCOFROC, 2001, 132–135). The model recognized more explicitly the need for substantial data acquisition and archiving

and resulting database development, and for greater interactions between local climate information user, provider, and intermediary groups.

To meet these needs, we have developed Rainwatch as a stand-alone, prototype geographic information system (GIS) that monitors West Africa’s rainfall and tracks seasonal rainfall attributes that are crucial for its farmers. Information delivery is based on Rainwatch automating and streamlining key aspects of rainfall data management, processing, and visualization. Rainwatch now has been demonstrated successfully to climate information provider and intermediary organizations in Niger, and so is being extended to user groups there and elsewhere in West Africa beginning with the 2009 rainy season.

IMPORTANCE OF RAINFALL. Sub-Saharan Africa (SSA) depends more strongly and directly on rainfall than any other region on Earth. Approximately 65% of the labor force (FAO 2006) and 95% of the land use (Rockström et al. 2004) in the region are devoted to agriculture, and overwhelmingly to rain-fed agriculture. Additionally, agriculture contributes, on average, about one-third of the gross domestic product (GDP) for SSA countries, compared to about 14% for developing nations elsewhere (Barrios et al. 2003). In spite of such strong rainfall dependence, SSA ranks among the lowest in the world in the density of rainfall monitoring stations and access to/use of instrumental rainfall data. Even where rainfall data are available, weeks can elapse between collection and accessibility to users (Bowden and Semazzi 2007). This delay significantly diminishes the usefulness and value of the data for many applications, including monitoring of dry spells, heavy rain events and flooding, and irrigation planning and management. These deficiencies in rainfall data management and dissemination stand in stark contrast to impressive advancements in seasonal rainfall forecasting for SSA (e.g., RCOFROC 2001; www.cpc.ncep.noaa.gov/products/african_desk), as well as vibrant discussions on the most effective packaging and use of the forecasts (e.g., Tarhule and

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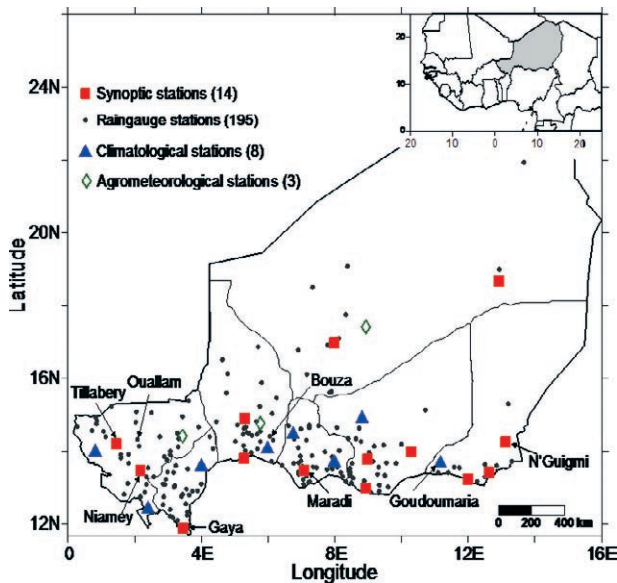


FIG. 1. Niger's meteorological stations and provincial boundaries. The capital city (Niamey) is the eighth province (see text) and contains synoptic (Aero) and rain gauge (Ville) stations. Data for named stations are presented in Fig. 3.

Lamb 2003; Amissah-Arthur 2005; Verdin et al. 2005; Rancoli 2006; Thornton 2006). Such limitations in rainfall data availability and use may affect stakeholder perceptions and adoption of climate forecasts, imperiling this promising development.

Responsibility for climate monitoring in SSA rests with the National Meteorological and Hydrological Service (NMHS) of each country. Consequently, improving rainfall data management and dissemination requires enhancing the capacity of NMHSs to acquire, process, and disseminate rainfall data rapidly, efficiently, and—ideally—in a manner that adds value for stakeholders. Since Rainwatch was developed using Niger (Fig. 1) as a case study, we first describe the current climate data collection and dissemination process in that nation. We next explain how these NMHS procedures, which are typical for West Africa as a whole, shaped the rationale and conceptual requirements for the design of Rainwatch. Finally, we describe briefly the architecture and operation of Rainwatch.

CURRENT RAINFALL MONITORING IN NIGER. The Direction de la Météorologie Nationale du Niger (DMNN) is the primary agency responsible for all weather and climate monitoring activities in Niger. The DMNN's rainfall monitoring operations

fall into three categories: data collection, data analysis and archiving, and rainfall information dissemination. Although Niger's rain gauge network comprises 220 stations, only 14 are synoptic stations, 3 are agrometeorological stations, and 8 are climatological stations (Fig. 1). The remaining stations are rain-gauge (only) sites maintained by volunteer observers, mainly teachers and local police officers. The U.S. National Weather Service's Cooperative Observer Program (www.weather.gov/om/coop) is also operated by volunteers. Niger's total network is concentrated predominantly in the wetter and more populous southern Sahel zone (12°–15°N) that supports some agriculture.

The 14 synoptic stations are required to transmit hourly data via telex and phone throughout the year to DMNN's Operations Office in Niamey, using equipment provided for that purpose. During the rainy season (May–October), all other stations with telephone or radio telecommunication facilities are required to transmit daily data directly to the DMNN's Climatology Division when rainfall is recorded. The number of stations involved generally ranges between 10 and 50, depending on the spatial extent of the rain, and seems to be increasing due to cell phone use. Additionally, at the end of each month, hard copies of the data collected at every station are mailed to DMNN for quality control, analysis, and archiving.

DMNN develops several rainfall information and weather products at different temporal scales. During the rainy season, rain amounts at up to 20 gauge sites are read over national and local radio during the evening news. This information is complemented by weather segments on national television newscasts, the reception of which is limited to major urban areas. Seasonal labor migrants rely on these broadcasts, especially at the beginning of the rainy season, to plan their itineraries (Tarhule and Lamb 2003).

Another major DMNN product is a bulletin series titled *Dekadal Agro-Hydro-Meteorological Bulletin for Monitoring the Growing Season*. These bulletins are issued for 10/11-day nonoverlapping periods (dekads) from 1 June to 31 October. For each dekad, the bulletin provides station information for approximately 130 stations on total rainfall and cumulative season-to-date rainfall, comparisons of those totals with previous year counterparts, and the deviation of the cumulative rainfall from the current WMO 30-year normal. DMNN uses these analyses to classify rainfall as normal, below normal, or above normal for the eight provinces of Niger (Fig. 1). The bulletin for a given dekad generally is available to “established

user groups” (government agencies, nongovernment organizations) 2–4 days after the dekad ends, both in hard copy and on the DMNN Web site (www.meteo-niger.net). DMNN also prepares a *Special Bulletin for Policy Makers* that is issued twice during the rainy season. The first edition, usually in early August, provides an overview of the rainy season onset throughout the country and an early evaluation of the seasonal climate forecast produced by the West Africa Climate Outlook Forum (PRESAO). Around 30 September, the second issue reviews the quality and progress of the rainy season.

All DMNN *Special Bulletins* are made available to the national committee for early warning systems and disaster management (Comité Nationale du Systeme d’Alerte Précoce et de Gestion des Catastrophes, CN/SAP) and are posted online at www.meteo-niger.net/html/meteo.htm. CN/SAP combines the DMNN rainfall information with that from international early warning systems [i.e., Global Information and Early Warning System (GIEWS), Famine Early Warning System (FEWS), Early Warning and Agricultural Productions Forecast Project (AP3A)] and socioeconomic indicators such as food staple prices, to publish a monthly bulletin titled *The Food, Socio-Economic, Health and Nutritional Conditions Information Bulletin*. This bulletin describes the spatiotemporal rainfall distribution, highlighting areas of rainfall deficit or surplus, and identifies regions of greatest drought and food shortage risk. The committee uses the information to make early warning decisions and to advise the international community about famine likelihood.

The above procedure has several limitations. Apart from the daily radio broadcasts, DMNN requires 12–14 days to release rainfall data that are processed to any degree. This delay includes the dekad rainfall aggregation period plus 2–4 extra days for data processing and dissemination. The 2–14 day interval between data collection and information release to the public reduces the utility and value of the information. An obvious example is for water stress on plants that tolerate less than 14-day dry periods, such as irrigated garden vegetables. By comparison, the U.S. National Weather Service website (<http://water.weather.gov/about.php>) reports observed precipitation amounts daily, and more frequently during periods of intense or severe weather. Additionally, dekad aggregated data can conceal important temporal characteristics and patterns in rainfall variability. The DMNN use of dekads simply continues a tradition established in

the early 1970s—very early in what became a multi-decadal drought—that then was considered adequate for dryland agricultural production (e.g., millet, grain sorghum, groundnuts). This practice is at variance with the nuances of drought stress that have emerged from the subsequent prolonged exposure to that hazard. At the opposite end of the water hazard spectrum, such temporal aggregation and associated information delay weakens flood risk assessment for the region (Tarhule 2005).

RAINWATCH CONCEPT AND DESIGN.

Rainwatch is designed to help alleviate such limitations in West African rainfall data acquisition, management, representation, and dissemination. As shown below, attainment of the full potential of Rainwatch will require maximizing the number of observers who transmit their data to DMNN every day, and daily keying of those data into Rainwatch. The implementation of Rainwatch therefore should catalyze this necessary national infrastructure change. This altered practice also would permit selected observers at key locations, if equipped and trained appropriately, to operate Rainwatch for their stations and so act as outreach posts for local and regional rainy season status information. Presently, the observers have no rainfall tracking capabilities. This change would increase local awareness of, interest in, and ultimately appreciation for systematic rainfall information. The flexibility of Rainwatch’s displays, relative to the long-term DMNN emphasis on dekads and departure statistics, further increases this potential.

Based on interviewing several hundred farmers in four West African countries (Tarhule and Woo 2002; Tarhule and Lamb 2003), it is clear that they are most comfortable assessing and describing rainfall conditions in an analogue manner by comparison with some previous reference period or year. Only rarely did discussion involve the magnitude of departure from a statistic. Rainwatch was conceived and designed to operate within this worldview. It relies heavily on cumulative daily rainfall plots to show rainfall attributes typically of interest to farmers, including the starting date, ending date, and duration (length) of the rainy season. Other attributes treated are the frequency and intensity of rain events, spatial rainfall distribution, occurrence of dry spells, and rainfall totals for periods during the season and for the entire season. To identify and visualize analogue years or locations, the cumulative daily rainfall curves for those years (sites) are plotted on the same graph.

TABLE 1. Classification of rainfall status in RAINWATCH.

Percentile threshold	Rainfall status	USAID FEWS
$x_i < 10$	Very dry	Dry
$10 < x_i \leq 20$	Dry	
$20 < x_i \leq 50$	Moderately dry	Normal
$50 < x_i \leq 80$	Moderately wet	
$80 < x_i \leq 90$	Wet	Wet
$x_i > 90$	Very wet	

This simple approach highlights differences or similarities in the above temporal rainfall characteristics in a manner that is quite intuitive and therefore easy to visualize and understand.

Outside the research community, a majority of rainfall data users across SSA tend to qualitatively categorize rainfall status as dry (drought), normal, or wet. Rainwatch uses six percentile levels as thresholds to separate these conditions (Table 1). The percentiles are defined based on seasonal cumulative daily rainfall (x_i) for the period 1965–2000. To simplify computation and development, this reference period is fixed in the present version of Rainwatch. However, future versions will give users the flexibility to specify other desired reference periods. The thresholds in Table 1 are broadly consistent with those used by USAID FEWS to classify rainfall across SSA as dry, normal, or wet. They also reflect recommendations that the 10th and 90th percentiles are appropriate thresholds for monitoring extreme dry and wet conditions (e.g., Nicholls and Murray 1999; Svoboda et al. 2002).

THE RAINWATCH PROGRAM. The present prototype version of Rainwatch makes use of ESRI’s inbuilt libraries. Developed in Visual Basic (VB), Rainwatch comprises a local, relational database created in Microsoft Access™ and a VB program, which is used to customize several functions in ArcGIS™ desktop and MapObjects™ interactive windows that facilitate communication between the user and the program.

The database comprises two tables. The first table stores information on the identification attributes of the rain-gauge stations included in the database, including the station identification (ID) number or code, name,

geographic coordinates, and a reference number. The second table holds the daily rainfall data (1965–2007) obtained for each station from DMNN. The two tables are linked using the Station ID field, which they share in common. To preserve database integrity, inbuilt security measures ensure that only the system administrator can access and manipulate the database.

The VB program is the heart and brain of Rainwatch. When executed, the program presents a “Login” window requesting a valid user name and password. Once successfully logged on, users are presented with a “Map View” showing the spatial domain and locations of all gauging sites for which rainfall data are available in the database (Fig. 2). Holding the mouse over any station activates a pop-up window identifying the station name. Clicking on any station opens up a “Viewer by Station” interactive window, which allows the user to view a cumulative daily rainfall plot for one year (or part of a year) against up to five percentile thresholds for the reference period.

For the example in Fig. 3a, the user has selected one station during the severe drought year 1984 and all five thresholds. The plots show that the cumulative daily rainfall curve for 1984 ultimately tracked the 10th percentile, but rainfall was close to the median from the beginning of the season (23 May) until 18 June. However, two dry spells depressed the curve to the 10th percentile by 21 August and the season ended 13 days earlier than the median. For the entire season, 1984 rainfall totaled only 310 mm compared to a median of about 500 mm. All this information can be visualized at a glance. The charts and maps produced can be saved and exported as various graphic file formats. Command functions allow seamless navigation to other windows and components of the program. For example, the “Compare Sites/Years” button allows users to compare cumulative daily rainfall plots for several years at the same site or for several stations for the same year.

Figure 3b provides further evidence that the 1984 rainfall season, despite starting on time and showing early promise, became very poor compared to other years. Additional inferences and follow-up analyses can be made from this chart, including for the frequencies of rain events, heavy rainfall, and dry spells. The spatial extent of the 1984 drought is documented further in Fig. 3c. In principle, the number of sites and/or years that can be visualized simultaneously is limited only by the size of the database. The comparison of sites can involve a different year for each station. In practice, however, overexploitation of

this potential can make the final chart cluttered and difficult to interpret. All charts and maps produced can be saved and exported in commonly used graphic file formats.

An “Areal Rainfall” option displays the spatial rainfall distribution across the area covered by the database for any selected day. Spatial rainfall interpolation is achieved using universal kriging. However, the resulting isohyetal patterns need to be interpreted with care in areas with low rain gauge density. Clicking on the “Database” command option opens the database in tabular form to list all stations with their periods of data availability. A convenient feature of the database is that it is dynamic—as new data are added, the database updates automatically to include all active linked charts and graphics. Thus, once a database has been created, it should be simple to keep it updated and current.

Rainwatch is designed explicitly for African rainfall data management, visualization, and dissemination, by harnessing the capabilities of GIS, computers, and internet technology. The software licenses and system requirements needed to use Rainwatch depend on user sophistication. “As is” application will require the following software and licenses: MS Access, ArcEngine Runtime Core, ArcEngine Runtime Spatial Analyst Extension, and Map Object. Users who wish to modify or otherwise customize Rainwatch also will need MS Visual Basic and the ArcEngine Developer Kit for COM. We recognize that the requisite software and licensing costs may prohibit widespread adoption of Rainwatch at this time. However, the present prototype version was not designed for mass use, but instead explicitly for organizations like the African Centre of Meteorological Applications for Development (ACMAD, in Niamey, Niger) and the NMHSs that are more likely to have access to the needed software. We expect that licensing difficulties in West Africa will diminish gradually as GIS software and its use become more widespread among relevant agencies and institutions in the region. Additionally, the further development of Rainwatch will assess the utility of free GIS software.

A major appeal of Rainwatch is its simplicity—all interactive interfaces, symbols, and names used are unpretentious and self explanatory. In our application testing, including within Niger as described below, new users required only 10 minutes to become comfortable with the program and navigate through its components. Most importantly, test users of Rainwatch could follow the program’s logic and fully

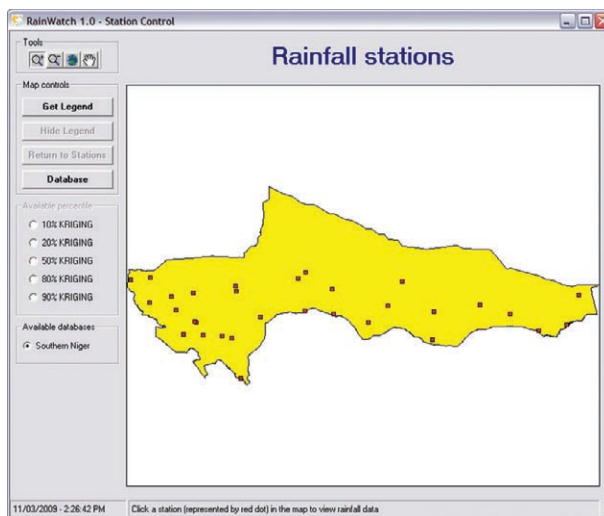


FIG. 2. Rainwatch station viewer page presented on successful login. The application lists the available databases the user may access, at present only Southern Niger. Pausing the mouse over the stations shown activates a pop-up box identifying the station. Helpful instructions appear at the bottom of the window pane.

understand and interpret the graphics they produced. Accordingly, this easy-to-use and locally oriented tool should complement the more remotely generated rainfall products currently available from FEWS NET African Data Dissemination Service (<http://earlywarning.usgs.gov/adds>) and the satellite-based NOAA/NWS/NCEP Climate Prediction Center’s RFE rainfall estimates and climatology (www.cpc.ncep.noaa.gov/products/african_desk). With further improvements and expansion, Rainwatch can become the African counterpart to Australia’s RAINMAN (www2.dpi.qld.gov.au/rainman).

DEMONSTRATION, MODIFICATION, AND ADOPTION OF RAINWATCH.

In late 2007, overview presentations on Rainwatch were made at the Second International Conference of the African Monsoon Multidisciplinary Analysis (AMMA) project (Karlsruhe, Germany) and at ACMAD, where the audience included representatives of several other Niamey-based meteorological organizations. The strong interest expressed in Rainwatch at those presentations led to several comprehensive hands-on demonstrations of its capabilities in Niamey during early August 2008 to representatives of ACMAD, DMNN, the Niger River Basin Authority (NBA), AGRHYMET, and the Université Abdou Moumouni de Niamey.

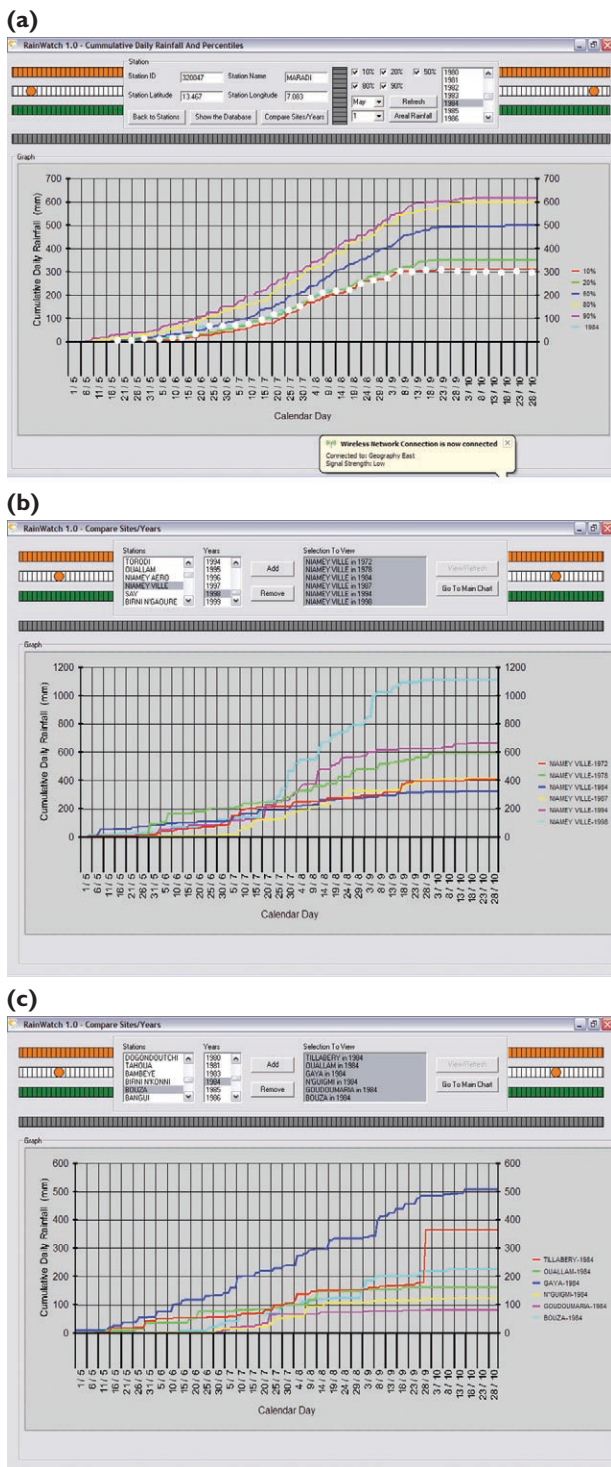


FIG. 3. The interactive Map View interface showing (a) cumulative daily rainfall for 1984 at Maradi (white dots, described in text) against historical percentile thresholds there; (b) cumulative daily rainfall for six contrasting years at Niamey Ville; and (c) comparison of cumulative daily rainfall at six stations (Gaya, Tillabery, Bouza, Goudoumaria, N’Guigme, Woullam) for the same year (1984). Abscissa is labeled in day/month.

These demonstrations resulted in both the immediate “as is” installation of Rainwatch at ACMAD, which will serve as the coordinating agency and dissemination point in West Africa, and excellent suggestions for enhancing Rainwatch’s utility. The particularly desired additional Rainwatch capabilities included increased flexibility for users to specify criteria that are more directly tailored and suitable for their application or location (e.g., rainy season onset/cessation and wet/dry spell duration) using readily available criteria (reviewed in Segele and Lamb 2005). Additionally, test participants suggested a capability to export time series of events generated in Rainwatch to spread sheets for further analysis. Also seen as desirable were capabilities to trigger an early warning once a threshold is exceeded; generate rainfall statistics for specified time periods; access and visualize station metadata more explicitly; couple season-to-date monitoring with PRESAO seasonal forecasts for verification and rest-of-season scenario development; and effectively deploy the system for educational purposes. The major concerns expressed by some participants were about possible GIS software licensing and related constraints, and the need to expand the database to include other hydroclimatic variables such as temperature, streamflow, and soil moisture.

We now have begun the Rainwatch upgrades suggested above, and some were operational by the May start of the 2009 West African rainy season. Licensing and related issues for ACMAD’s use of Rainwatch also were resolved satisfactorily by that time, through actions taken by the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) at the University of Oklahoma. However, only strong indigenous effort can overcome the constraints on Rainwatch application and use that stem from the spatial domain and density of the supporting database. For the prototype version discussed here, this domain covers only Niger. Furthermore, it is anticipated that ACMAD, as an early Rainwatch adopter, will lead the efforts to obtain needed databases for most of West Africa and other parts of SSA in the next few years.

CONCLUDING REMARKS. Rainwatch can especially benefit an NMHS by forcing increased automation of its rainfall data acquisition and database management. The end products of automatic chart generation and visualization, and their societal dividends, will only be possible if an NMHS significantly reduces the considerable time that now extends from


data collection and processing to information release to stakeholders. As noted earlier, the availability and potential benefits of Rainwatch should catalyze the needed national infrastructure improvements. Because Rainwatch is an attempt to help Africa help itself, there is a requirement for Africa to “step up” as well. That would permit Rainwatch to be used either at the head office of the national monitoring agency to rapidly process and disseminate rainfall information, or by climate outreach and agricultural extension services to add value to rainfall data by providing analogue comparisons and climatic context. Other potential users include researchers, the media, individuals, and educational institutions.

Ultimately, the plan is to convert Rainwatch into a Web-based application, making it available to anyone with Internet access. By design, most novice computer users can operate the program within about 10 minutes. Hence, Rainwatch can be used in combination with other climate data dissemination initiatives, including local radio, even in rural areas. Because it is simple to operate and more streamlined in design and scope than existing rainfall data dissemination systems, Rainwatch may be adopted and used more widely where other more complicated systems have had limited success. We are very encouraged that ACMAD has taken the lead in adopting and implementing the program.

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