Current status on flood forecasting and early warning in Africa

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Published online: 10 Mar 2011.

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Research paper

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ABSTRACT
An overview of the current state of flood forecasting and early warning in Africa is provided in order to identify future user needs and research. Information was collected by reviewing previously published research in the scientific literature and from institutional websites. This information was supplemented by data collected from a questionnaire sent to hydrological and meteorological institutions that were identified as potentially dealing with flood management issues in Africa. Results show that there are a significant number of institutional flood forecasting initiatives ongoing in Africa, but information regarding many of these initiatives is not easily accessible. Second, there is a clear need for improved flood forecasting and early warning in Africa. Third, the dissemination of existing flood forecasts and warnings to end-users and the public could be improved. It should be noted, however, that due to the difficulty in obtaining information regarding flood forecasting in Africa, the overview presented by the authors might be an underestimation of the current situation. Finally, the authors demonstrate the importance of developing a complementary flood forecasting and early warning system.

Keywords: Flood management; flood forecasting and early warning; Africa

1 Introduction

Riverine flood events account for nearly half of the deaths and one-third of all economic losses from natural hazards worldwide (United Nations Educational, Scientific and Cultural Organization (UNESCO) 2008). Between 1985 and 2005, riverine floods claimed the lives of over 112,000 people, affected more than 354 million people and caused approximately 520 billion euros (US$690 billion) in financial damages (Bakker 2006). In 2004, the United Nations Development Programme (UNDP) estimated that on average almost 200 million people in more than 90 countries are exposed to catastrophic flood events every year (United Nations Development Programme, 2004). The vulnerability to floods is expected to rise in the future due to climate change and the steady increase of population as well as of urbanization (Kundzewicz 2008).

In Africa, the occurrence of severe flood events has increased noticeably over the last years, affecting millions of people and hampering economic development in the region, exerting enormous pressure on the affected countries (Dartmouth Flood Observatory 2010, EM-DAT 2010). Therefore, considerable effort has been put into the mitigation of flood-induced damages in Africa over the last decade. During this period, there has been a significant and rapid increase in Africa in the number of institutions and research dedicated to dealing with flood management. The increased focus on flood management in Africa has the potential to significantly improve flood management in the region; however, the increased number of different institutions involved also complicates the coordination of research and implementation efforts. A clear understanding of what work is being undertaken by different groups is therefore critical for an efficient coordination of work as well as future knowledge and data sharing. Therefore, in this study, a trilingual questionnaire (in English, French and Portuguese) was sent to African institutions in order to compile an empirical database on the current state of flood forecasting in Africa. The aim of the questionnaire was to identify the needs on flood forecasting and warning for Africa and to identify the existing gaps for future research.

Effective flood forecasting and early warning systems are an essential part of flood risk management, by providing additional preparation time prior to a flood event. At present, there are a number of initiatives trying to extend flood forecasting and warning lead time through continental or global-scale early warning systems. The European Flood Alert System (EFAS) – an advanced prototype of a continental flood alert system – is an example of such systems. EFAS uses several deterministic and ensemble weather forecasts to produce probabilistic flood alerts with lead times of up to 15 days (Thielen *et al.* 2009). Systems such as EFAS may have potential for applications in Africa. This is facilitated by the large-scale approach of the EFAS-underlying hydrological model LISFLOOD (Thielen *et al.* 2009), its ability to cope with limited amount of input data, the increased lead time of up to 15 days and its clear, concise and unambiguous visualization and decision support products. Such a continental system could facilitate the flood management on a national level and also improve the coordination of international aid. For these reasons, the development of this type of system for Africa has recently gained increased attention in the political and scientific environment (The Lisbon Declaration on 'GMES and Africa' 2007).

This paper is organized into an introduction and five sections. Section 2 consists of a review of previously published research. Journal articles were reviewed to track the development of flood management in Africa over the past two decades; while web-based information was used to provide a brief outline of current transnational flood forecasting initiatives in Africa. Section 3 provides a detailed evaluation of the outcome of the questionnaire survey, which is intended to complement the limited amount of information available in journal articles and online sources. This section provides an overview of the operational flood forecasting institutions in Africa and an in-depth view on the field of flood forecasting, as well as the expressed user needs of the institutions participating in the survey. Finally, in Section 4 a summary of the study's findings is given. Section 5 consists of conclusions, and Section 6 contains an outlook for future work.

2   Review of previously published research

2.1   *Flood management in Africa since 1990*

The number of English language scientific articles addressing flood management topics in Africa has steadily increased over the past two decades (Figure 1). This indicates an increase in the attention given to flood concerns in the region.

With respect to the geographic locations of studies conducted since 1990, documented flood-related research has been conducted predominantly on the Nile (Andah and Siccardi 1991, El-Fandy *et al.* 1994, Shamseldin *et al.* 1999, Artan *et al.* 2007b) Niger (Youdeowei 1990, Gobo and Abam 2006) and Senegal (Albergel *et al.* 1991, Albergel *et al.* 1997, Bader *et al.* 2006, Sandholt *et al.* 2003) river basins. After the year 2000,
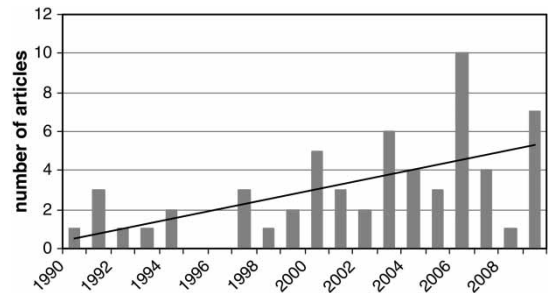

Figure 1   Number of scholarly articles dealing with flood management issues in Africa since 1990 (Elsevier B.V. *SCOPUS* 2010)

studies have been conducted in the Okavango (Neuenschwander *et al.* 2002, Wolski *et al.* 2006), Limpopo (Khandlhela and May 2006, Asante *et al.* 2007) and Orange ('Flood forecasting and management' 2004) river basins. Flood management research in other large, transnational river basins, such as the Congo, Juba-Shabelle, Lake Chad, Volta and Zambezi, have had very little representation in the scientific literature.

Previous research can be classified into the following four groups: (I) hydrological modelling, (II) flood control and mitigation, (III) flood forecasting (and early warning) and (IV) flood disaster management. The highest concentration of articles falls under the category of flood disaster management (IV), with a focus on evaluating the potential use of remote sensing techniques for flood monitoring (Neuenschwander *et al.* 2002, Sandholt *et al.* 2003, Seiler *et al.* 2009, Asante *et al.* 2007) and examining different damage and vulnerability assessment techniques (Du Plessis and Viljoen 1998, Khandlhela and May 2006). The second highest frequency of studies focus on hydrological modelling (I), particular those assessing the technical feasibilities of flow modelling (Walsh *et al.* 1994, Albergel *et al.* 1997, Wolski *et al.* 2006, Artan *et al.*, 2007a).

Flood forecasting (category III) in Africa has not received extensive attention in the scientific literature, despite the recognized importance of the topic. A number of authors, including Al-Zu'bi *et al.* (2010), Artan *et al.* (2007a), Grimes and Diop (2003), Li *et al.* (2008) and Yawson *et al.* (2005), have commented on the importance of medium- to long-range flow forecasts as essential tools for an optimal use of water resources; while high-quality real-time or relatively short-range flow forecasts are considered indispensable to mitigate catastrophic losses to life and property and to improve the efficiency of hydroelectric dams and other water management operations.

Previous flood forecasting studies focus almost entirely on applications on the Nile River Basin. A summary of the main findings from all flood forecasting studies are presented in the following.

(a) Medium- to long-range flow forecasts:
- El-Fandy *et al.* (1994) applied autoregressive integrated moving average (ARIMA) time-series model to process 1-year-ahead forecasts to predict the water levels of the seasonal Nile floods in Cairo, Egypt. Results were stated to be fairly promising. The ARIMA model was able to

track the historical flood levels, thus, indicating an adequacy of the model.

- Wang and Eltahir (1999) used Bayesian analysis for developing a discriminant flow-forecasting algorithm based on forecasted El-Nino-Southern Oscillation (ENSO), precipitation over Ethiopia and recent Nile flow measurements for qualitative medium- and long-range forecasting on the Nile floods, given as probabilities. They found that ENSO information is the most important data source for long-range forecasts,[1] while precipitation and discharge information improve the medium-range forecast[2] skill.

- Eldaw *et al.* (2003) investigated the use of the sea surface temperature in the oceans and the previous year of Guinea precipitation, for quantitative long-ranging forecasts with lead times of 4–16 months for the flood season of the Blue Nile. Models that use inter alia correlation analysis, multiple linear regression and principal component analysis were applied. The study found that forecasts are most accurate if they are processed in the preceding season, while forecast accuracy decreases with increasing lead time.

- The Centre for Ecology and Hydrology (IHE) developed a flow forecast model for the Somalian part of the Juba-Shabelle River Basin, called Somalia FFM. The system utilizes upstream measurements and simple regression equations to predict river levels and flows at key gauging stations. Fry *et al.* (2002) stated the system to be reliable for flow forecasts with a lead time of up to 1 week.

(b) Real-time or relatively short-range flow forecasts:

- The use of satellite-based rainfall estimation for real-time river flow forecasting, with 1 day of lag time, was evaluated by Grimes and Diop (2003) using the Bakoye catchment in Mali as an example. This study concluded that if contemporaneous calibration from rain gauges were available for the calibration of the hydrological model, the combination out of CCD-only (cold cloud duration) and MR (multiple linear regression algorithm) rainfall estimates improved the accuracy of river flow forecast when comparing with using rain gauge data alone. However, they state that their results were not reliable enough for immediate operational implementation.

- Li *et al.* (2008) evaluated the applicability of real-time TRMM-based multi-satellite analysis for an operational flood prediction system, supporting the disaster management capacity in Nzoia Basin (Lake Victoria). Within the study, the TMPA real-time rainfall data were used to calibrate Xinanjiang (Zhao *et al.* 1980), the applied hydrological model. Continuous discharges forced by TMPA real-time data were calculated for a 5-year time period and compared against benchmark values, which were obtained in the pre-process using rain gauge and observed stream flow data. The performance of the benchmark approach is reasonable according to statistical indices such as bias ratio or the Nash-Sutcliffe Coefficient of

Efficiency. Further, the study found significant improvement in model performance by incorporating systematically bias-corrected TMPA rainfall data. Although the results justify the use of TMPA data for flood prediction purpose, the authors stress the importance of further investigations for integrating remote sensing data into a real-time hydrological modelling system.

- Al-Zu'bi *et al.* (2010) developed the Takagi-Sugeno fuzzy model to estimate the Nile river flow at the Dongola station in Sudan. The performance of the model was assessed using observed discharge records of almost two decades. The results of the training and testing phase had a high VAF (variance-accounted-for) value indicating good modelling capacities. Within the study, it is demonstrated that the fuzzy model is able to represent the river flow at Dongola better than traditional modelling approaches and outlined the potential of their approach to provide accurate forecasts, in time and quantity.

2.2 *Current flood forecasting projects*

The amount of web-based information available addressing ongoing transnational flood forecasting and early warning initiatives in Africa is relatively limited in comparison with other continents. Only eight initiatives that fall into the category were found, which are described below.

2.2.1 *Flood forecasting initiative*

The FFI is one of the two major flood-forecasting initiatives that operate under the auspices of the World Meteorological Organization (WMO). It is a global network-building endeavour that was launched in April 2003, which currently incorporates 58 countries and over 300 participants from national meteorological and hydrological services. Its ultimate aim is to improve the domain of flood forecasting and warning by enhancing the capacity of meteorological and hydrological services to jointly deliver timely and more accurate products and services to decision-makers and the general public (World Meteorological Organization 2009).

The FFI is based on the analysis of capabilities and shortages of current flood forecasting systems in the member countries. Based on six regional workshops and one global conference, the 'Strategy and Action Plan for the Enhancement of Cooperation between National Meteorological and National Hydrological Services for Improved Flood Forecasting' has been developed and released in 2007 as a mean to achieve the above-stated objectives (World Meteorological Organization 2010). Within this plan, the core activities that need to be addressed to improve the overall chain of hydrological forecasting were identified:

- improvement of the meteorological and the hydrological forecasting practices and products;

- enhancement of the ability of national hydrological and meteorological services, as well as of countries sharing a river basin, to coordinate and cooperate effectively;
- promotion of training and capacity-building within the hydrological and meteorological services; and
- formulation of guidelines related to flood forecasting and warning (World Meteorological Organization 2007).

Additional implementation of pilot projects at various administrative levels facilitate the identification of technical and administrative difficulties and demonstrate the value of an increased collaboration between national meteorological and hydrological services in flood forecasting (World Meteorological Organization 2010).

In Africa, the FFI has started pilot projects in the Nile River Basin as well as in Ghana, identifying the technical and administrative challenges as well as future needs.

2.2.2   *Associated Programme on Flood Management (APFM)*

In August 2001, the APFM was launched jointly by the WMO and the Global Water Partnership. It promotes the concept of Integrated Flood Management (IFM), as a subset of Integrated Water Resource Management, to foster sustainable development of water resources (Associated Programme on Flood Management 2006).

In the first phase (2002–2006) of the programme the principles of IFM were established, 'best practices' identified and implementation tools developed. The developments of this phase are a product of the endeavours of various stakeholders communicating jointly using the APFM provided platform. In the second phase (since 2007), the APFM has encouraged the implementation of the IFM concept globally, though the initiation of pilot projects in various countries such as Bangladesh, Brazil, India, Kenya, Nepal, Poland, Romania, Slovakia, Uruguay and Zambia (Associated Programme on Flood Management 2006).

In Africa, the APFM facilitates the *Kenyan Ministry of Water Resources Management and Development* as well as the *Zambian Ministry of Energy and Water Development* to develop an IFM strategy for Lake Victoria (Associated Programme on Flood Management 2004) and the Kafue Basin (Associated Programme on Flood Management 2007), respectively. These strategies include explicit recommendations concerning the development of flood forecasting systems as a means to reduce flood-induced damages, by addressing flood forecast formulation and dissemination issues. In addition to these pilot studies, the APFM holds five African case studies located in Cameroon (Associated Programme on Flood Management 2003), Ethiopia (Associated Programme on Flood Management 2003), Mali (Diarra *et al.* 2004), Mauritania (Hamerlynck and Duvail 2004) and Zimbabwe (Madamombe 2004), which focus on different aspects of flood management in specific (Associated Programme on Flood Management 2010).

2.2.3   *Flood Risk and Response Management Information System (FRRMIS)*

FRRMIS has been run operationally since October 2009 by FAO-SWALIM (Somalia Water and Land Information Management Project (FAO-SWALIM) 2010). It provides freely accessible information for the Juba-Shabelle River Basin about inter alia historical floods, flood-prone areas and currently flooded areas. The information is used by all Somali Inter Agency Standing Committee clusters (WASH, Livelihood, food, health, etc.), local and international NGOs and Donors (Gadain and Jama 2009).

Additionally, FAO-SWALIM produces in collaboration with USGS and FEWS NET Somalia flood forecasts at key river gauging stations in the Juba-Shabelle River Basin with up to 2 weeks' lead time. These are released weekly in the Flood Watch Bulletin, which is disseminated directly to a number of end-users (e.g. UN agencies, international and local NGOs), but also freely accessible on the website for any other user (Artan *et al.* 2007a).

2.2.4   *Early Warning and Humanitarian Emergency Information Center (EWHIC)*

The EWHIC is a national service, run by the Republic of Sudan. As the FAO-SWALIM, they also process flood forecasts at key river gauging stations in the Blue Nile with lead times of up to 4 days. These alerts have been published in a flood watch bulletin since July 2009 at irregular intervals of every few days. The bulletins are freely accessible on the Humanitarian Aid Commission website (Humanitarian Aid Commission 2010).

2.2.5   *SERVIR-Africa*

SERVIR-Africa is a novel initiative launched by the *National Aeronautics and Space Administration* (NASA), the *Regional Center for Mapping of Resources for Development* (RCMRD) and the *Water Center for the Humid Tropics of Latin America and the Caribbean* (CATHALAC) in November 2008. It focuses on the development of an integrated platform for data and service discovery, acquisition, sharing and use. The SERVIR-Africa platform is currently under development. However, once the basic infrastructure is established, SERVIR plans to address flood management services and applications such as flood potential mapping, flood forecasting and post-event flood mapping, all at a $0.25°$ resolution (SERVIR-Africa 2010).

2.2.6   *African Early Warning and Advisory Climate Services in Africa (ViGIRisC Africa)*

ViGIRisC Africa is a continental project, which has been launched by the African Center of Meteorological Applications for Development (ACMAD) in 2009. This endeavour intends to focus on the support of products and services of vigilance related to climate risk in different areas where vulnerability is high. ACMAD identified floods as severe and high-impact

weather phenomena, which can be mitigated through strengthening early warning systems. Therefore ViGIRisC aims at identifying, highlighting and supporting best practices, for which reason an exhaustive review of early warning systems is currently carried out (African Center of Meteorological Applications for Development 2010).

2.2.7 *Global Flood Alert System (GFAS)*

GFAS is an internet-based information system, developed since March 2006 by the Japanese *Infrastructure Development Institute*, to process information such as rainfall maps and heavy rainfall information that can be utilized for flood forecasting and warning (Infrastructure Development Institute 2006, International Flood Network 2006).

The GFAS retrieves once a day the TRMM-based satellite precipitation estimates (3B42RT) of NASA which are posted every 3 h and calculates the daily and 3-day precipitation map at a resolution of $0.25°$. These precipitation maps are compared against estimated precipitation of 5- and 10-year return period that have been calculated in a preliminary process. If the real-time precipitation estimates exceed these values, notifications for heavy rainfall are sent out automatically via email to registered meteorological and disaster management services in the area of concern to draw attention to possible flood occurrence. In addition, the GFAS enables access to the daily precipitation data of the past 10 days (Infrastructure Development Institute 2006).

Currently, the system operates on a trial basis, with specific focus on the verification of the satellite real-time precipitation estimations with ground-based observations (Infrastructure Development Institute 2006).

2.2.8 *NASA Global Flood Detection System (FDS)*

The global FDS is a real-time flood management tool that has been run operationally by NASA since 2006. The system implements real-time TMPA-based rainfall data along with topography, land cover and soil property data into the Natural Resources Conservation Service – Curve Number model to calculate the water level for a spatial coverage between $50°N$ and $50°S$. Together with the water level, a metric value for flood potential is generated that identifies areas at flood risk (Moffitt *et al.* 2011).

The validation of the FDS has recently been quantified by Moffitt *et al.* (2011). Their study showed that the overall probability of FDS to detect floods is high. However, the reliability of the system can vary depending on the season and drainage basin characteristics. Moffitt *et al.* (2011) noticed an increase in false alarms during the monsoon period and in regulated basins.

For the future, NASA plans to enhance the accuracy of FDS by incorporating a physical-based hydrological model specifically to support real-time decision-making on flood management (Moffitt *et al.* 2011).

2.2.9 *Early Warning System for Flood Events*

Since 2006, the *Information Technology for Humanitarian Assistance, Cooperation and Action* (ITHACA) has been developing an Early Warning System for Flood Events. The main target of this project is the development of an automatic, simplified and efficient procedure for the detection of potentially flooded areas based on a near real-time satellite rainfall product, at a worldwide extent (Albanese *et al.* 2008, ITHACA 2008).

The methodological approach currently tested is broadly similar to the one used by GFAS. The ITHACA Early Warning System retrieves 3B42RT data instantaneously as soon as they are released by NASA. These near real-time data are then compared against river basin-specific critical pluviometric thresholds, which were determined in a preliminary process based on historical flood events using 3B42 precipitation data and depth–duration–frequency curves. If the 3B42RT rainfall values exceed the basin-specific threshold, the area of concern will be indicated on a map as potentially flooded. The length of lead time of the flood warning depends on the lag time between heavy rainfall and peak discharge, which varies for each river basin (Albanese *et al.* 2008, ITHACA 2008).

Once the testing phase is finalized, ITHACA plans to automatically visualize the potentially flooded areas within a web application, allowing easy access to end-users (Albanese *et al.* 2008).

3 Questionnaire

The information presented in Section 2 demonstrates that previously published research provides only a scattered and incomplete picture of flood forecasting and early warning in Africa. Based on this information alone, a holistic view, in terms of completeness and timeliness, cannot be achieved. Therefore a trilingual questionnaire survey titled 'Current Status of Flood Forecasting and Early Warning in Africa' (Appendix 2) has been customised to serve the following three purposes:

(1) to give an overview about institutions that are working in the domain of flood management in Africa;
(2) to evaluate the current state of flood forecasting and early warning; and
(3) to outline the needs of a flood forecast system, as expressed by the participating institutions.

More than 500 questionnaires were distributed to hydrological and meteorological institutions that were identified as potentially dealing with flood management issues in Africa (approximately two-thirds within Africa, approximately one-third outside Africa). In response, 65 questionnaires were returned, from 56 different institutions (47 African, 9 non-African institutions). The spatial scale of the respondents' work ranged from global to continental, to a single-basin or country projects in scope.
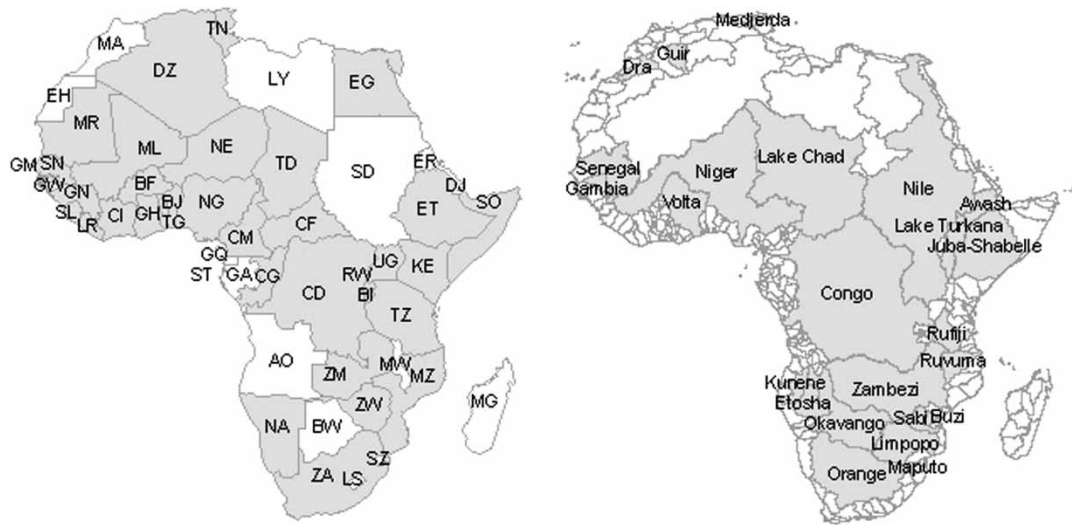
Figure 2   Target regions of the participating institutions; countries (left) and river basins (right)

In total, 35 countries and 24 river basins are represented, covering a large portion of Africa (Figure 2).

As shown in Figure 2, the distributions of questionnaires returned for this study have a good coverage across the continent, suggesting a representative sample of data. It is important to note, however, that participation in the questionnaires was voluntary on the part of the participants. Therefore, those institutes that took part in the survey do not necessarily provide a representative sampling across all institution types queried for the survey. Regardless, given the lack of alternate sources of data available in the region, the results of the questionnaire are expected to provide a valuable source of insight into the state of flood forecasting in the region, which would otherwise be unattainable.

3.1   *Institutes dealing with flood management*

Appendix 1 provides an overview of the 56 participating institutions that responded to the study questionnaire. These include governmental and non-governmental organizations (e.g. Direcção Nacional de Águas, Cruz Vermelha de Mocambique, etc.), river basin authorities (e.g. Volta or Niger Basin Authority) and universities (e.g. Université Cheikh Anta Diop or University of Dar es Salaam).

In addition, the table contains information about the institute-specific target area, their respective flood management activities and the links to the institutional websites, facilitating the access to supplementary information.

3.2   *Current status of flood forecasting and early warning*

Thirty-nine out of the 56 participating institutions work within the field of flood forecasting and early warning. The institutions indicated not only their specific flood forecasting methods but also the existing linkages to end-users of the information, which will be evaluated in detail below.

Table 1 summarizes the technical specifications of the flood forecasting methodology, the applied hydrological model and the meteorological data used by participating institutions. With regard to the forecasting methodologies, it shows that there are a variety of methodologies applied, with a slight emphasis on rainfall–runoff modelling, closely followed by the statistical analysis. Almost two-thirds of the rainfall–runoff models rely on physical-based relations, while black-box and hybrid models account equally for the rest. For the spatial composition of the hydrological models, there is a slight emphasis on semi-distributed structure. Focusing on the meteorological data, observations and also satellite data are most commonly used, while radar data are applied the least. Further, one-third of the participating institutions indicated that they use deterministic and probabilistic forecasts. Finally, more than half of the institutions generate their hydrological forecasts relying not only on precipitation data, but also on temperature and other meteorological variables such as humidity and wind.

Five well-known hydrological models can be identified that are applied by a variety of different institutions to process flood forecasts for different target areas in Africa. These are as follows:

(1) *Galway Flow Forecasting and Modelling System (GFFMS).* GFFMS is a software package of the National University of Ireland (Monomoy 2005). It is applied in an operational modus by the Kenya Meteorological Department, SWALIM and the Ministry of State for Special Programmes (Kenya) to process flood forecasts with lead times of up to 3 days for the Nzoia, Juba-Shabelle and Lake Victoria Basin, respectively. Besides that, the University of Dar es Salaam tests the performance of this system for Tanzanian catchments as part of their postgraduate research work.

(2) *MIKE BASIN (MB).* MB is a decision support tool for integrated water resources management planning, developed by DHI Water & Environment (Danish Hydraulic Institute

Table 1 Flood forecasting and early warning specifications

Forecasting methodology					
Downstream routing with upstream measurements		17			
Statistical analysis		24			
Rainfall-runoff modelling		27			
Hydrological model					
Type	Physical	16	Spatial composition	Distributed	8
	Black-box	4		Semi-distributed	13
	Hybrid	6		Lumped	10
Meteorological data					
Source	Observations	33	Variables (forcings)	Precipitation	36
	Radar	8		Temperature	18
	Satellite data	23		Others	12
	Deterministic forecast	13			
	Probabilistic forecast (EPS)	13			

2003). It is applied by the Niger Basin Authority, ARA-Zambeze, Directorate of Water Resources Management (Uganda), Water Resources Management Authority (Kenya) and ARA-Sul for launching flood forecasts for the Niger, Zambezi and Lake Kyoga Basin as well as for Kenya and Mozambique. Although these institutions indicate that they run this model operationally, no specific lead times were provided.

(3) *GeoSpatial Stream Flow Model (GeoSFM)*. GeoSFM is a physical-based, semi-distributed model developed by the US Geological Survey (Artan *et al.* 2007b). It facilitates the Ministry of State for Special Programmes (Kenya), ARA-Sul and Centre Régional AGRHYMET to predict floods with a maximum lead time of 3 days for catchments located in Kenya, Mozambique and Western Africa.

(4) *HEC-HMS*. HEC-HMS is a hydrological modelling system developed by the Hydrological Engineering Center (HEC) of the US Army Crops of Engineers (Hydrological Engineering Center 2009). Using this system, flood forecasts for catchments in Burundi, Ethiopia and Egypt are released by the Institut Geographique du Burundi, Addis Ababa University and Water Resources Researches Institute (Egypt). The lead time varies between 12 h for small-scale mountainous catchments in Ethiopia to 3 days for the Nile River Basin in Egypt.

(5) SWAT (Soil and Water Assessment Tool). SWAT is a hydrological modelling tool developed by USDA Agriculture Research Service (Neitsch *et al.* 2005). The Université Cheikh Anta DIOP, the Water Resources Researches Institute and the University of Dar es Salaam assess the potential of SWAT as future flood forecasting tool using catchments in Senegal, Egypt and Tanzania.

In addition to these well-known hydrological models, many others such as the US National Weather Service River Forecast System (NOOA's National Weather Service 2005) or GR4J

(Perrin *et al.* 2003) have also been applied by a minor number of institutions to produce flood forecasts.

The potential benefit of a flood forecast information increases with the lead time (Butts *et al.* 2006). Out of the 29 institutions that currently run their system in an operational mode, 24 specified their lead times. The lead times reported are depicted in Figure 3, which show an emphasis on short-range forecasts with lead times of up to 3 days, as well as long-range forecasts with lead times of 14 days and more. Figure 3 also reveals that there are almost no medium-range forecasts with lead times between 5 and 11 days. This does not reflect the information about the usage of probabilistic meteorological forecasts as summarized in Table 1. A possible explanation for this difference could be the fact that some organizations qualitatively use the information of a probabilistic meteorological forecast, but do not actually use them in a quantitative hydrological forecast model, as is common practice in some European hydrological services.

However, the most accurate and timely flood forecasts have no benefit if the forecast information is not used effectively to initiate prevention and mitigation measures (Butts *et al.* 2006). In order to do so, an efficient collaborative network between information provider and end-user is indispensible.
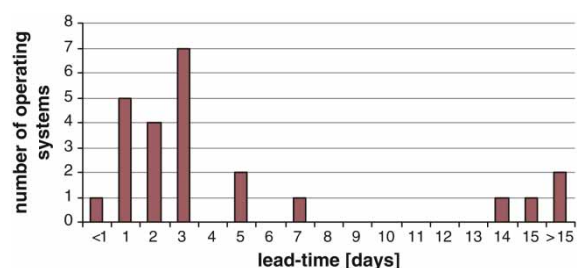

Figure 3   Flood forecasting lead-time in the institutions responding to the questionnaire

Table 2 Provider and end-users of flood forecasting information

End-users	Provider
Disaster management agencies/units	ARA-Centro, Direcção Nacional de Águas, Namibia Meteorological Service, Niger Basin Authority, Volta Basin Authority, Water Resources Management Authority (Lake Victoria), Western Kenya Flood Mitigation Project, Zimbabwe National Water Authority
Government, national water resource agencies	Agence Nationale des Ressources Hydrauliques, Kenya Meteorological Department, Western Kenya Flood Mitigation Project, Nile Forecast Centre, Université Cheikh Anta Diop, Volta Basin Authority
Hydrological services	AGRHYMET Regional Centre, Commission Internationale du Bassin Congo-Oubangui-Sangh, Volta Basin Authority
National meteorological services	African Centre of Meteorological Applications for Development, Commission Internationale du Bassin Congo-Oubangui-Sangh
NGOs	African Centre of Meteorological Applications for Development, AGRHYMET Regional Centre, ARA-Centro, Kenya Meteorological Department, Somalia Water and Land Information Management Programme
Basin authorities	African Centre of Meteorological Applications for Development
Managers of hydraulic systems	Commission Internationale du Bassin Congo-Oubangui-Sangh, Department of Water Affairs (Luska), Department of Water Affairs (Zambia), Niger Basin Authority
Ministry of transport, navigation services	ARA-Centro, Commission Internationale du Bassin Congo-Oubangui-Sangh, Department of Water Affairs (Luska), Niger Basin Authority
Research centres, universities	Commission Internationale du Bassin Congo-Oubangui-Sangh, Department of Water Affairs (Zambia), UNESCO-IHE, University Cheikh, University of Da es Salaam, University of Gezira
Local community, general public	Agence Nationale des Ressources Hydrauliques, AGRHYMET Regional Centre, ARA-Centro, Direccao Nacional de Aguas, Department of Water Affairs (South Africa), Lake Victoria, Namibia Met Service, ONG GLOBE, Senegal National Met Agency, Somalia Water and Land Information Management Programme

Almost all institutions that provide operational flood forecasts mentioned having multiple end-users. These are split up into a variety of different end-user categories that include governmental and non-governmental institutions, research centres and the general public, as seen in Table 2. For each category, the respective providers are listed.

As shown in Table 2, a significant network currently exists in Africa between the providers of flood forecasting information and end-users. Particularly, dense collaborative networks are present in the Niger and Zambezi River basins, as well as in Kenya. However, it is important to consider that a higher density of networks will not necessarily result in improved operational flood protection, unless the information provided is effectively used by the end-user. For example, in the questionnaires, a number of flood forecast providers indicated that although they know that their end-users could benefit from the information they provide, they are uncertain of how effectively this information is actually utilized. Therefore, there is room for improvement in the dissemination of flood forecasts and warnings, amongst others and improved effective collaboration between the data providers and end-users.

4   Needs for flood forecasting and early warning systems

The institutions participating in the questionnaire also communicated their needs on flood forecasting and warning. Three main needs were identified, which are the need for:

- a (complementary) flood forecasting and early warning system,
- technical expertise, and
- increased funds.

Fifty-two out of the 56 institutions expressed their interest in a (complementary) flood forecasting and early warning system. The remaining four institutions that were not interested are exclusively non-African institutions that carry out flood forecasting studies in Africa themselves.

The lead times that are desired by the institutions range fairly homogeneously from 1 to 2 days up to more than 10 days (Figure 4). Slight emphasis is on forecast information with a lead time of 3–6 days, possibly due to their potential to complement the partly available short-range forecasts of 1–3 days.

Additionally, numerous institutions expressed their need for training to develop skills for flood forecasting, focusing on both the technical part of hydrological modelling and on the skills needed to effectively interpret the resulting information. Lastly, some institutions stated that their initiatives are severely hampered by a lack of financial resources and expressed their need for increased funds to cover research and implementation expenses.
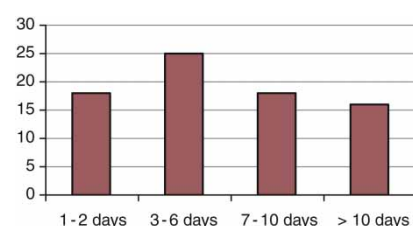

Figure 4   Desired lead-time of flood forecasts

5 Conclusions

In this study, the current status of flood forecasting and early warning in Africa was examined. Open accessible resources provided only limited information on the status of this topic, and therefore a questionnaire survey was used to collect additional information. The questionnaire gave also further insight to technical specifications as well as to management issues.

The results show that there are a significant number of institutional initiatives currently active in the region. However, information regarding many of these initiatives was not publicly accessible, which may result in an underestimation of the amount of flood forecasting activity being undertaken in Africa by the wider scientific community.

The questionnaires revealed that there is a significant variability in the amount of resources available, both in equipment and technical expertise, across different institutions in Africa. On the one hand, there are endeavours that are fairly well equipped; while on the other hand there are numerous initiatives that are significantly hampered by a lack of technical and financial means.

This study has shown that there are a number of initiatives that have good potential for future developments, but that there are still a number of needs that must be met to advance flood forecasting in the region. Almost all African institutions that participated in the survey confirmed that a complementary flood forecasting and early warning system would add value to their work. Furthermore, numerous institutions stated a need for improved technical expertise to set up and launch flood forecasts, as well as for processing and interpreting the resulting information.

Finally, the importance of improving collaboration between the provider and the end-user of flood forecast information has been revealed by this study. Although initial collaboration has been partially established in many cases, this network needs to be expanded and deepened in order to increase the potential value of flood forecasts and to decrease flood-induced damages.

6 Future outlook

Future research and implementation efforts have to be focused on meeting the above-stated needs. In this context, the Joint Research Centre (JRC) has recently carried out a feasibility study in the Juba-Shabelle River Basin to test the transferability of the EFAS methodologies for equatorial African river basins (Thiemig *et al.* 2010). Flood events were detected in a hindcasting mode in more than 85% of all investigated cases, with an average lead time of 6–8 days. The results demonstrated successfully that the methodologies have the capability to produce probabilistic medium-range forecasts for African basins, which are yet not available (Figure 3), but desired (Figure 4) and therefore can provide added value to the current flood management practice. However, it has to be kept

in mind that conventional (deterministic) and state-of-the-art probabilistic flood forecasting are significantly different methods. It takes time and training to get probabilistic forecasting accepted and received well by local basin authorities, decision-makers and even many flood forecasters themselves. In Europe, this process of launching probabilistic forecasts has been ongoing for around 10 years and is becoming more and more accepted at the operational level. This was realized through various consultation meetings, trainings and several years of pre-operational testing of probabilistic forecasting. Applying these techniques in Africa makes similar efforts necessary, before these techniques could be used in an operational mode. In addition, the final dissemination of a flood warning to local authorities and the population, as well as training of the latter to trigger an appropriate action following a flood warning, will be even more crucial than in Europe.

Capacity-building in the form of collaboration and networking is encouraged in Africa, by international programmes such as the UN-SPIDER, INBO and WMO. These initiatives need to receive increased political and economical support.

In future, the chain of flood forecasting has to be increasingly considered as an entity, including the support of scientific research, technical training and on-site networking capacities.

Notes

1. Lead time longer than the hydrological response timescale; >2–3 months (Wang and Eltahir 1999).
2. Lead time shorter than the hydrological response timescale (Wang and Eltahir 1999).

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Appendix 1. List of participating institutes dealing with flood management in Africa (activities: (I) hydrological modelling, (II) flood control, (III) flood forecasting (and early warning) and (IV) flood disaster management)

No.	Institute	Target country**/region (river basin)	I	II	III	IV	Web site
1	Addis Ababa University (AAU)	ET	x		x		www.aau.edu.et
2	African Centre of Meteorological Applications for Development (ACMAD)	Africa			x	*	www.acmad.ne
3	Agence Nationale des Ressources Hydrauliques (ANRH)	DZ	x		x		www.anrh.dz
4	AGRHYMET Regional Centre	BF, CV, GM, GW, ML, NE, MR, SN, TD (Lake Chad, Niger, Senegal, Volta and Gambie)	x		x	x	www.agrhymet.ne
5	ARA-Centro	MZ, ZW (Pungwe, Buzi, Sabi)	*	*	x	*	–
6	ARA-Sul	MZ	x	x	x		www.ara-sul.co.mz
7	ARA-Zambeze	MZ (Zambezi)			x		www.arazambeze.gov.mz
8	Autorite pour la protection contre les inondations de la plaine d'Antananarivo	MG (Ikopa)			x		www.mineau.gov.mg
9	CEREG Massif Central	(Senegal, Volta, Niger and Gambie)	x				www.cereg-mc.com
10	Commission Internationale du Bassin Congo-Oubangui-Sangha (CICOS)	CM, CF, CG, ZR (Congo)	x		x	x	www.cicos.info
11	Congo Bureau of Agronomics Studies Environmental and New Technology (COBASEN)	ZR (Malebo and Ndjili)			x		–
12	Coordination régionale des usagers des ressources naturelles du bassin di Niger	BJ, BF, CM, CI, GN, ML, NE, NG, TD (Niger)			x		–
13	Cruz Vermelha de Mocambique (CVM)	MZ				x	www.redcross.org.mz
14	Department of Water Affairs: Lusaka Province	ZM (Lower Zambezi, Luangwa and Kafue)		x	x		–
15	Department of Water Affairs: South Africa	ZA (Orange, Limpopo and transboundary rivers)	*	*	x	*	www.dwaf.gov.za/Hydrology
16	Department of Water Affairs: Zambia	ZM (Lunsemfwa and Luangwa)	x	x	x	x	www.mewd.gov.zm
17	Direcção Nacional de Águas (DNA) – Departamento de Gestão de Recursos Hídricos	MZ (all basins)		x	x		www.dnaguas.gov.mz
18	Direction Générale des Ressources en Eau	TN (Mejredah, Cape Bon Méliane)		x		x	–
19	Directorate of Water Resources Management, Ministry of Water and Environment	UG (Lake Kyoga)	x				www.mwe.go.ug/DWRM
20	University of the Free State, Disaster Risk Reduction Research Centre (DiMTEC)	ZA			x	x	www.ufs.ac.za
21	East African Community (EAC)/Lake Victoria Basin Commission (LVBC)	BI, RW, KE, TZ, UG (Lake Victoria)					www.lvbcom.org
22	Food and Agriculture Organization, Somalia Water and Land Information Management Programme (SWALIM)	SO (Juba-Shabelle)	x	x	x	x	www.faoswalim.org
23	ICSU Regional Office for Africa	Sub-Saharan Africa					www.icsu-africa.org
24	Institut Geographique du Burundi (IGEBU)	BI	x				–
25	Instituto Nacional de Gestao de Calamidades (INGC)/Centro Nacional Operativo de Emergencia (CENOE)	MZ				x	www.ingc.gov.mz
26	International Relief and Development (IRD)	MZ				x	www.ird-dc.org/what/countries/mozambique.html
27	Kenya Meteorological Department	KE (Nzoia)	x	x	x	x	www.meteo.go.ke
28	Météo-France	(SN)					www.meteofrance.com

Appendix 1. Continued

No.	Institute	Target country**/region (river basin)	I	II	III	IV	Web site
29	Agence du Bassin du Fleuve Niger (ABFN)	ML (Niger)		x		x	www.environnement.gov.ml/index.php?page=agence-du-bassin-du-fleuve-niger-abfn
30	Western Kenya Flood Mitigation Project (WKCDD&FMP)	KE (Lake Victoria, Nzoia)	x	x	x	x	www.westernkenya.go.ke
31	Namibia Meteorological Service	NA			x		www.meteona.com
32	National Hydrological Services, Department of Water Affairs	NA	x		x		www.mawf.gov.na
33	National Meteorology Agency of Ethiopia	ET (Wabe-Shebele = Juba-Shabelle)			x		www.ethiomet.gov.et
34	National Meteorology Agency of Senegal	SN (Senegal)		x	x	x	www.meteo-senegal.net
35	National University of Rwanda (NUR)/ Civil Engineering Department	RW (Akagera)		x	x		www.nur.ac.rw
36	Niger Basin Authority (NBA)	BJ, BF, CM, CI, GN, ML, NE, NG, TD (Niger)	*		x		www.abn.ne
37	Nile Forecast Center (NFC)	EG (Nile)	x	x	x		www.emwis-eg.org/recersh%20%20and%20devolpment%20-%20other-1%20-Nile%20Forecast%20Center.htm
38	ONG GLOBE	MR (Senegal)	*	*	*	*	–
39	PADEF	RDC		x			–
40	RCMRD	KE (Nzoia)	x		x	x	www.rcmrd.org
41	SOGREAH	Global	x	x	x	x	www.sogreah.fr
42	South African Weather Service	ZA (Limpopo, Vaal, Orange)			x		www.weathersa.co.za
43	UNESCO-IHE Institute for Water Education	Global	x		x		www.unesco-ihe.org
44	UNESCO-IHP	Sub-Sahara Africa	x		x	x	www.unesco.org/water/ihp
45	Union du Fleuve Mano	LR, SL, GN, CI (transnational rivers)					www.manoriverunion.in
46	Université Cheikh Anta Diop	SN (Senegal)	x	*	x	*	http://fst.ucad.sn
47	University of Dar es Salaam, Department of Water Resources Engineering	TZ (9 river basins)	x		x	x	www.wrem.udsm.ac.tz
48	University of Gezira	SD		x	x		www.uofg.edu.sd
49	Volta Basin Authority (VBA)	GH, BF, TG (Volta)	x		x		www.abv-volta.org
50	Water Resources Management Authority (WRMA), Lake Victoria North Catchment Area (LVNCA)	KE (Nzoia)		x	x	x	–
51	Water Resources Management Authority (WRMA)	KE	x				www.wrma.or.ke
52	Water Resources Researches Institute, Hydrologic Department	EG (Nile)	x	x	x	x	www.wrri.org.eg
53	World Food Programme (WFP)	West Africa				x	www.wfp.org
54	World Meteorological Organization (WMO)	(Zambezi and Rufiji)			x	x	www.wmo.int
55	Zambezi River Authority	ZM, ZW (Zambezi)		x	x		www.zaraho.org.zm
56	Zimbabwe National Water Authority (ZINWA)	ZW (Sabi, Buzi and Pungwe)	x		x		www.zinwa.co.zw

*Discrepancy between multiple statements from the same institute.
**Countries specified with ISO code.

Appendix 2

EUROPEAN COMMISSION
DIRECTORATE-GENERAL JRC
JOINT RESEARCH CENTRE
Institute for Environment and Sustainability
Land Management & Natural Hazards Unit

Questionnaire: *"Current status on flood forecasting and early warning in Africa"*

Name of institution (department)/ agency:

Target area (country, river basin):

Area of activities:

- ☐ hydrological modelling
- ☐ flood forecasting (and early warning)
- ☐ other
- ☐ flood control
- ☐ flood disaster management

If your institute / agency is involved in flood forecasting, please specify:

a) Methodology:
- ☐ downstream routing with upstream measurements
- ☐ rainfall-runoff modelling
- ☐ statistical analysis
- ☐ other

b) Hydrological model:
Name:
Type:
- ☐ physically-based
- ☐ black-box
- ☐ hybrid
- ☐ lumped
- ☐ distributed
- ☐ semi-distributed

Short description:

c) Meteorological data:
Source:
- ☐ radar data
- ☐ satellite data
- ☐ deterministic forecast
- ☐ probabilistic forecast (EPS)
- ☐ observations
- ☐ other

Variables:
- ☐ precipitation
- ☐ temperature
- ☐ other

d) Lead-time: _____ day(s)

e) Is the system operational?
- ☐ yes
- ☐ no

f) By whom are the information used so far?

g) Links to additional information:

Your needs on flood forecasting and early warning:

a) Would an early flood warning system be useful?

☐ yes
☐ no

b) Which lead-time would you require?

☐ 1 – 2 days   ☐ 7 – 10 days
☐ 3 – 6 days   ☐ > 10 days

Is there any other institute involved in flood forecasting and early warning in the same target area?
(if yes, please state the name of the institution, the link to the web-site or any other available contact information)

Contact details for the person in charge of the flood management (forecasting):

Name:
E-mail:
additional:

Additional information or comments:

In case we have further questions, may we contact you via e-mail?

☐ yes
☐ no

Would you be interested to receive updates on the current research status concerning a proposed Pan-African Flood Alert System?

☐ yes
☐ no

We gratefully acknowledge your participation in this questionnaire. For further information about our project do not hesitate to visit our web-site or contact us directly via email: Ad De Roo or Vera Thiemig.

If you wish to receive a copy of this questionnaire please enter your e-mail:

[Submit]   [Reset]

Declaration: The Land Management and Natural Hazard Unit (parent: Joint Research Centre, European Commission) will treat the information gained through this questionnaire confidentially and use it exclusively for research purpose.