Flood fatalities in Africa: From diagnosis to mitigation

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[1] Flood-related fatalities in Africa, as well as associated economic losses, have increased dramatically over the past half-century. There is a growing global concern about the need to identify the causes for such increased flood damages. To this end, we analyze a large, consistent and reliable dataset of floods in Africa. Identification of causes is not easy given the diverse economic settings, demographic distribution and hydro-climatic conditions of the African continent. On the other hand, many African river basins have a relatively low level of human disturbance and, therefore, provide a unique opportunity to analyze climatic effects on floods. We find that intensive and unplanned human settlements in flood-prone areas appears to be playing a major role in increasing flood risk. Timely and economically sustainable actions, such as the discouragement of human settlements in flood-prone areas and the introduction of early warning systems are, therefore, urgently needed. **Citation:** Di Baldassarre, G., A. Montanari, H. Lins, D. Koutsoyiannis, L. Brandimarte, and G. Blöschl (2010), Flood fatalities in Africa: From diagnosis to mitigation, *Geophys. Res. Lett.*, *37*, L22402, doi:10.1029/2010GL045467.

1. Introduction

[2] Torrential rains and flooding affected 600,000 people in 16 West African nations in September 2009. The worst hit countries were Burkina Faso, Senegal, Ghana and Niger. This event closely followed the 2007 floods that displaced more than a million people in Uganda, Ethiopia, Sudan, Burkina Faso, Togo, Mali and Niger, and claimed over 500 lives, and the 2008 flooding in Mozambique [*United Nations*, 2009]. These events, and the continually increasing number of people affected by flooding during the 2009–2010 rainy season, which numbered about 25,000 through April 20, are the most recent examples of the growing flood risk in Africa. In fact, the economic damages caused by floods as well as the number of people affected by them has substantially increased in recent decades [*Jonkman*, 2005]. The number of fatalities caused by floods in Africa during the period 1950–2009 [*Centre for Research on the Epidemiology of Disasters* (*CRED*), 2004], summarized in Figure 1a, dramatically shows that deaths have increased about one order of magnitude during the last 50 years. These numbers indicate a need for urgent actions, for the planning of which, we first need to understand the reasons why flood risk has strongly increased in Africa.

[3] Flood risk is determined by (a) the probability that a flood may occur and (b) the potential adverse consequences [*European Parliament and Council of the European Union*, 2007]. Therefore, herein we investigate the presence of climatic signals, which may have increased flood probability, as well as the land use, economic and demographic changes that may have led to increased human vulnerability to extreme hydro-meteorological conditions.

2. Flood Fatalities in Africa: A Climate Signal?

[4] Given the global perception that the severity and frequency of floods has increased in recent years [*CRED*, 2004] we examine if these perceived trends are supported by observational data collected in Africa. Many studies [*Kundzewicz et al.*, 2005; *Déry and Wood*, 2005; *McClelland et al.*, 2006; *Bates et al.*, 2008; *Petrow and Merz*, 2009; *Lins and Slack*, 1999; *Mudelsee et al.*, 2003; *Blöschl and Montanari*, 2010; *Villarini et al.*, 2009; *Di Baldassarre et al.*, 2009] have shown that it is difficult (if not impossible) to separate the effects of natural climatic fluctuations and human influences (e.g., land management practices, urbanization, deforestation, river training and embankment) on flooding, especially when analyzing individual river basins [*Blöschl and Montanari*, 2010]. To isolate a climatic signal in flooding, we need long-term runoff records, which should be both reliable and reasonably representative of natural river basin conditions. Therefore, we investigate trends in annual maximum discharge using a large, consistent and quality-assured database [*International Association of Hydrological Sciences*, 2003; *UNESCO*, 1984] from 79 gauging stations in Africa (Figure 2). The related African river basins remain largely undisturbed [*Sanderson et al.*, 2002] and are representative of diverse hydro-climatic conditions [*Hulme et al.*, 2001; *D'Odorico and Porporato*, 2006]. Thus, changes in their hydrological response may provide relevant information for detecting spatially (at the catchment scale) and temporally (at the time scale of the catchment response time) averaged climatic conditions.

[5] The observation period of the 79 time series, though variable, is subsumed within the time span from 1900 to 2000. The uncertainty of the river discharge data used in this study was found to be between 10 and 15% [*Herschy*, 2002], which is relatively low compared to the standard uncertainty of flood data [*Di Baldassarre and Montanari*, 2009]. The study area is characterized by different climatic regimes (the mean annual precipitation ranges from 90 to 1860 mm) and includes the main African rivers, such as Niger, Congo and Nile.

[6] A plot of specific discharge (i.e., standardized by the area of the catchment) values versus their year of occurrence,

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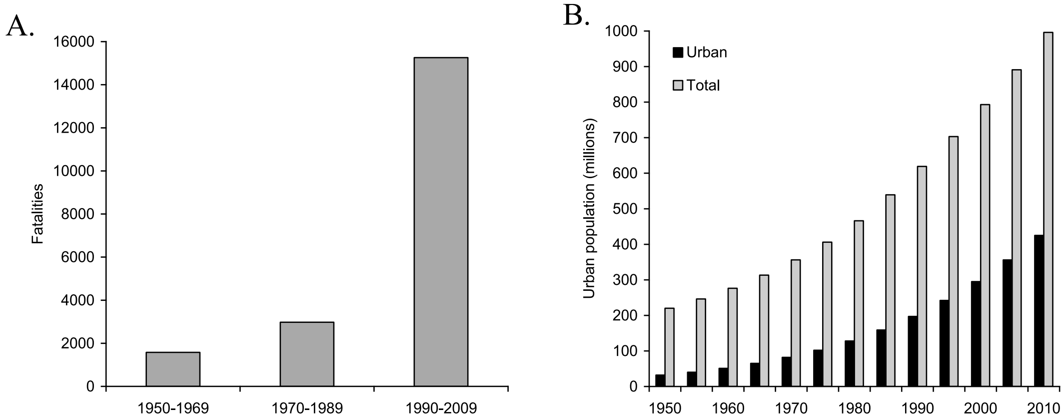

Figure 1. Inventory data for the African continent, 1950–2010. (a) Fatalities caused by floods [*CRED*, 2004]. (b) Total and urban population [*United Nations*, 2002].

for the entire African continent, is reported in Figure 3, for 30 African catchments with records of 30 years or more (up to 90 years). The catchments were separated into three categories according to their flood regime, each comprising 10 catchments: high flood rates with average specific annual peak discharge higher than 0.08 $m^3/s/km^2$; low flood rates with average specific annual peak discharge lower than 0.03 $m^3/s/km^2$; and medium flood rates with average specific annual peak discharge between these two values. The results of regression of the median (Figure 3) indicate that none of these changes are statistically significant ($p \leq 0.05$, even assuming independence of the series in time). The same procedure was also applied to subgroups of the database organized into three macro-regions according to climatic conditions (tropical, sub-humid, and semi-arid areas). Similarly, no significant trends were identified in any of these regions.

[7] The behavior of African floods during the Twentieth Century was further tested by analyzing individual time series of annual maximum flow using at-site linear regression. Results indicate that 65 out of 79 did not show significant ($p \leq 0.05$) trends, while of the remaining 14, only 4 had increasing trends (Figure 2). Understanding whether these local variations are simply fluctuations around a long-term mean [*Koutsoyiannis and Montanari*, 2007; *Cohn and Lins*, 2005] is difficult and beyond the scope of this study. However, it is worth noting that the efficacy of the concept of statistical significance with respect to trend testing is being increasingly questioned [*Koutsoyiannis and Montanari*, 2007; *Cohn and Lins*, 2005; *Clarke*, 2010], and less value

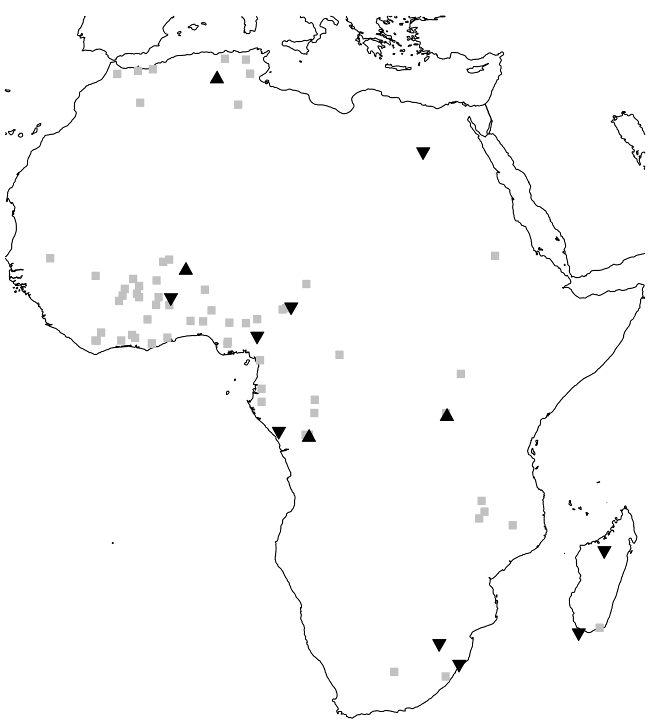

Figure 2. Location of African stream gauging stations used in this study, and the trends in annual maximum discharge determined ($p \leq 0.05$, for simplicity assuming independence of the series in time): upward triangles indicate an increasing trend, downward triangles a decreasing trend, and gray squares indicate no statistically significant trend.

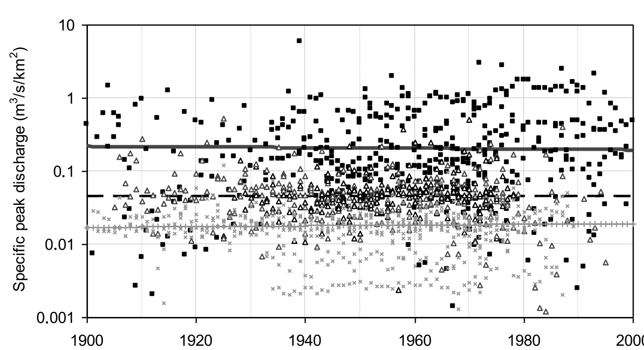

Figure 3. Analysis of flood data in Africa. Annual maxima of specific discharge and results of quantile regression (median) for catchments with: (i) high flood rates, average specific annual peak discharge higher than 0.08 $m^3/s/km^2$ (black squares); (ii) low flood rates, average specific annual peak discharge lower than 0.03 $m^3/s/km^2$ (x markers); and (iii) medium flood rates, average specific annual peak discharge between these two values (triangles). Trend lines for the annual medians of each of the three categories are also plotted (solid line, dashed line and line with crosses, respectively), which indicate no trends.

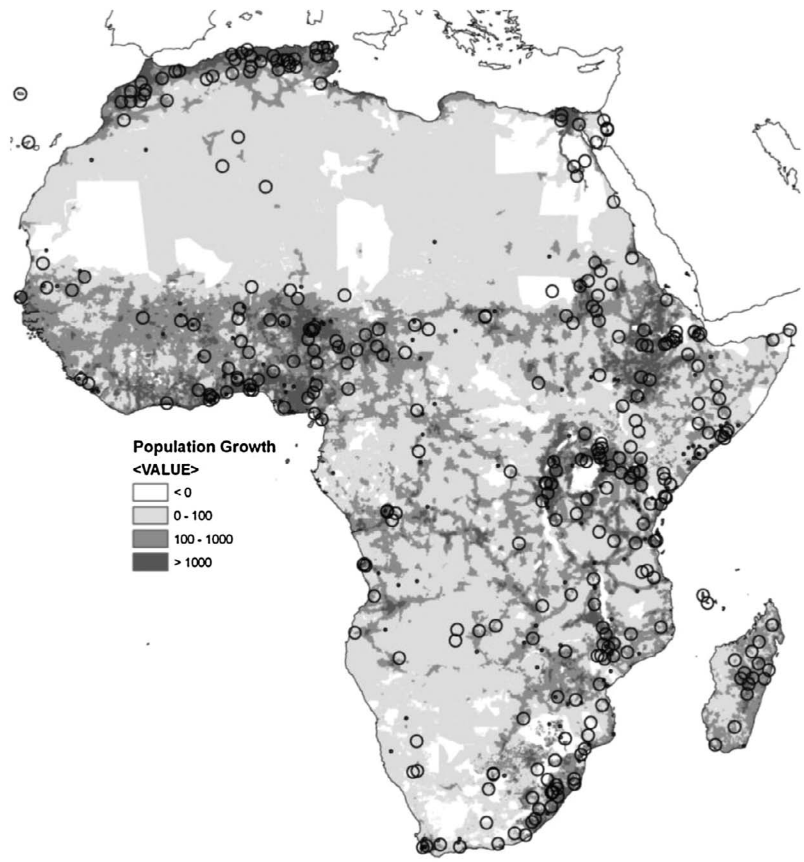

Figure 4. Spatial distribution of population growth (number of inhabitants per cell; resolution 2.5′) in Africa in the period 1960–2000; and location of floods (dots) and deadly floods (black circles) in the period 1985–2009.

should be ascribed to the purported "significance" of the trends than to their direction and magnitude.

[8] Based on the results of both continental and at-site analyses, we find that the magnitude of African floods has not significantly increased during the Twentieth Century (Figures 2 and 3), and that climate has not been a consequential factor in the observed increase in flood damage. This is consistent with the results previously obtained [*Kundzewicz et al.*, 2005; *Bates et al.*, 2008; *Petrow and Merz*, 2009; *Lins and Slack*, 1999; *Mudelsee et al.*, 2003] in different areas, such as North America, Europe, and Australia.

3. Flood Fatalities in Africa: Increased Vulnerability?

[9] Having detected no significant climate influence, the analysis focused on flood vulnerability. In the last 50 years, the African continent, as well as many other areas around the world, has undergone widespread and intensive urbanization. The total and urban population in Africa during the period 1950–2010 appears in Figure 1b [*United Nations*, 2002]. It is interesting to note that while the total population has increased by a factor of 4, the urban population has increased by one order of magnitude; approximately the same as the increase of fatalities caused by floods (Figure 1a). Since the earliest recorded civilizations, such as those in Egypt and Mesopotamia that developed in the fertile floodplains of the Nile and the Tigris and Euphrates Rivers, cities tend to be developed in flood-prone areas as they offer favorable conditions for human settlements and economic development [*Vis et al.*, 2003]. Thus, the intensive and unplanned urbanization in Africa and the related increase of people living in floodplains [*Hardoy et al.*, 2001; *Douglas et al.*, 2008] has led to an increase in the potential adverse consequences of floods and, in particular, of the most serious and irreversible type of consequence, namely the loss of human lives [*Jonkman*, 2005]. This can be shown, at the continental scale, by analyzing the dynamic of African population and the most recent deadly floods. For instance, Figure 4 shows the spatial distribution of population growth [*Nelson*, 2010] and the location of the latest floods, and deadly floods, in Africa (Dartmouth Flood Observatory, Global Archive of Large Flood Events, 2010, available at www.dartmouth.edu/~floods). It can be seen that most of the recent deadly floods have happened where the population has increased more. Furthermore, at the local scale, there are many examples of increased human settlements in floodplains [*Hardoy et al.*, 2001; *Douglas et al.*, 2008]. For instance, in Lusaka, the capital of Zambia, flood risk has strongly increased because of the fast growth of the city in flood prone areas [*Nchito*, 2007]. This is also the case of Alexandria in Egypt [*Klein et al.*, 2003], the Senegalese capital, Dakar, and the Burkina Faso's capital, Ouagadougou, strongly affected by the aforementioned 2009 flooding (auxiliary material).[1] Poorest people, in particular, often have

[1] Auxiliary materials are available in the HTML. doi:10.1029/2010GL045467.

had a limited choice and ended up living in high flood risk zones, such as riverbanks and coastlines, unaware of the risk and unprepared to react to floods [*Lutz et al.*, 2008]. This outcome is of serious concern given that the African population, as well as the percentage of population residing in urban areas, particularly in unplanned settlements, are still rapidly growing [*Lutz et al.*, 2008].

4. Mitigation Actions

[10] The findings above proffer viable opportunities to reduce loss of lives caused by floods in Africa. In particular, the introduction of flood forecasting systems, the building of population awareness and preparedness, urban planning and discouragement of human settlements in flood-prone areas, along with the development of local institutional capacities, are effective and socially sustainable actions that should be pursued with priority in the African continent. These actions can appreciably increase the societal capacity to cope with floods, thereby decreasing their overall impact. Recent positive experiences provide evidence of this. For instance, in 1977 a major storm caused some 20,000 deaths in the East Coast of India. After this catastrophe, an early warning system was established and when the same area was hit by an event of the same magnitude, in 1996 and 2005, the number of fatalities was 1000 and 27, respectively (International Council for Science, Science plan on hazards and disasters: Earthquakes, floods, and landslides, 2008, available at www.icsu-asia-pacific.org). Yet, in Czech Republic, as a result of the increased flood awareness and preparedness, the 2002 flood, although significantly larger than the previous one occurred in 1997, led to a much smaller number (one third) of flood-related fatalities [*Marešová and Mareš*, 2003]. To support these sustainable actions a great opportunity is offered nowadays by low-cost technologies, already available in many African countries, such as radio links from cellular communication networks, which, in addition to facilitating transmission of point measurements of rainfall and river flow, can be used to monitor path-averaged rainfall [*Leijnse et al.*, 2007], as well as emerging low-cost space-borne data that enable both rainfall measurement [*Li et al.*, 2009] and near real time flood monitoring [*Schumann et al.*, 2010].

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