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# Implications of climate change on hydrological extremes in the Blue Nile basin: A review

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ABSTRACT

*Study region:* The Blue Nile river basin in East Africa.
*Study focus:* This review paper presents the current understanding of hydrological extremes in the Blue Nile River basin under historic and future climate conditions, largely drawing on research outputs over the past decade. Characteristics of precipitation and streamflow extremes, including historic trends and future projections, are considered.
*New hydrological insights:* The review illustrates some discrepancy among research outputs. For the historical context, this is partially related to the period and length of data analyzed and the failure to consider the influence of multi-decadal oscillations. Consequently, we show that annual cycle of Blue Nile flow has not changed in the past five decades. For the future context, discrepancy is partially attributable to the various and differing climate and hydrological models included and the downscaling techniques applied. The need to prudently consider sources of uncertainty and potential causes of bias in historical trend and climate change impact research is highlighted.


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## 1. Introduction

Increasingly frequent and intense hydro-climatic extremes in recent decades are accelerating impacts on natural and human systems (IPCC, 2012). The first decade of the 21st century has seen an unprecedented number of extreme events in different regions of the world; for example, in the United States in 2011 alone there were 14 extreme events topping $1 billion in damages, including tornados, severe flooding, droughts, and fires (Coumou and Rahmstorf, 2012). Floods in

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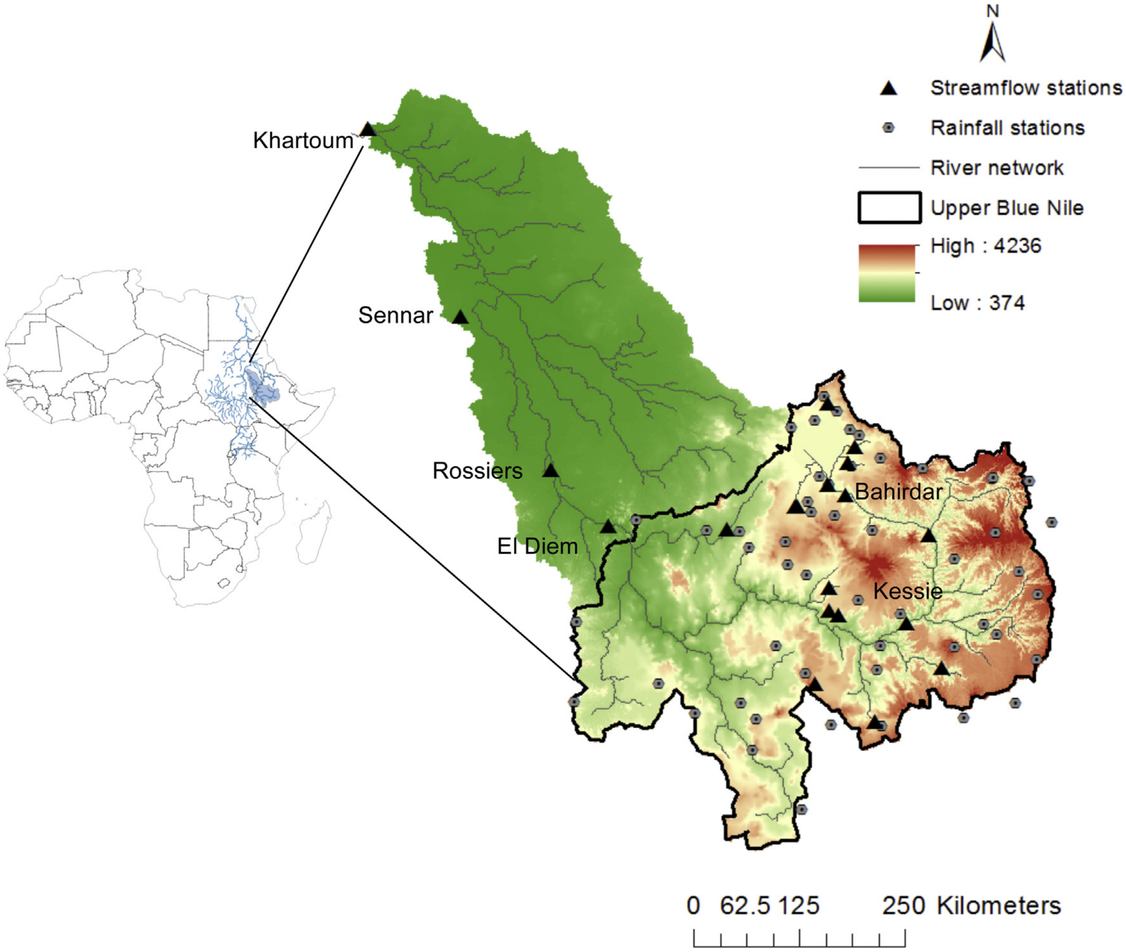


**Fig. 1.** Location of the Blue Nile basin in Africa and gauging stations used in the reviewed studies.

European rivers between 1998 and 2002 are responsible for the displacement of one-half a million people, 700 deaths, and in excess of 25 billion Euros in insured economic losses (Thielen et al., 2009). In response to such disastrous incidents, significant attention has been devoted to better understanding characteristics of hydrologic extremes and the potential association with non-stationary climate conditions. The Blue Nile River (BNR) basin in east Africa has been no exception, given its highly sensitive nature to precipitation variability at various time-scales and related hydrologic extremes.

The BNR basin is shared by Ethiopia and Sudan (Fig. 1) with an approximate drainage area of 312,000 $km^2$; the Ethiopian portion, the upper BNR basin, drains 176,000 $km^2$. The BNR exits Lake Tana in the Ethiopian highlands and travels 940 km to El Diem, near the Ethiopian Sudanese border, joined along the way by several important tributaries draining a large portion of western Ethiopia (Elshamy et al., 2009). In Sudan, the BNR receives water from two highly seasonal rivers, the Dinder and Rahad, and flows an additional 630 km to Khartoum, joining the White Nile (Awulachew et al., 2008). The upper BNR is the largest contributor to total Nile River flows, providing approximately 60% annually (Senay et al., 2014). Elevations in the basin vary from over 4000 m in the Ethiopian highlands to 350 m at the mouth (Awulachew et al., 2008).

Precipitation within the basin is highly seasonal, modulated primarily by the northward and southward migration of the Inter Tropical Convergence Zone (ITCZ), and to an extent, other large-scale oceanic-atmospheric drivers (Berhane et al., 2014; Block and Rajagopalan, 2007). Topography also influences precipitation patterns, although the relationship is not straightforward (Dinku et al., 2008). Annual precipitation rates in the highlands range from 800 to 2200 mm, with the majority falling during the June–September main rainy season known as "*Kiremt*", (Melesse et al., 2009). During this season erosion is considerable, contributing to loss of agricultural production in the Ethiopian highlands and excessive sediment in downstream countries (Betrie et al., 2011). The period October to May is usually a prolonged dry period with a short rainy season between March and May, known as "*Belg*". Climate change, specifically expected changes in the frequency and intensity of hydrological extremes (IPCC, 2012), is likely to exacerbate this, with implications across sectors, including subsistence rain-fed farming, large irrigation schemes, water supply, and hydropower generation, for both riparian countries.

In spite of the importance of the BNR to the entire Nile basin system, our knowledge regarding how large-scale climate patterns affect hydrologic extremes is not overly extensive. The El Nino-Southern Oscillation (ENSO) climate phenomenon,