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# Paleohydrology of extraordinary floods along the Swakop River at the margin of the Namib Desert and their paleoclimate implications

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ABSTRACT

The Swakop River is a major ephemeral river (drainage basin area about 30,000 $km^2$) crossing the western Namib Desert. Its hydrology and limited water resources depend on storms and floods. Therefore, the hydrology and flow regime in the Swakop River basin determines the availability of water for human use. In this study we present a millennia-long record of extreme floods, using paleoflood hydrological methods and optically stimulated luminescence (OSL) ages. The record includes 44 large floods ranging in date from the late Pleistocene to the present. The oldest six to eight floods are dated from the late Pleistocene to the mid-Holocene (between 14,900 ± 1700 and 5100 ± 620 years ago), with calculated peak discharges of 550–1280 $m^3 s^{-1}$. Eighteen floods, eleven of which were between 1000 and 1600 $m^3 s^{-1}$, occurred between 740 ± 90 and 190 ± 10 years ago. Additional 17 later floods occurred between about AD 1850 and 1963, with peak discharges between 100 and 1000 $m^3 s^{-1}$. The historical record which partly parallels the latter period recorded 17 large floods during the period 1893–1963. Flood frequency analysis (FFA) of the combined systematically gaged record (1963–2003) and the paleoflood record since AD 1270 (740 ± 90 years, the most complete record), was applied using the maximum likelihood method. A two-component extreme value distribution (TCEV) estimates the 1% annual exceedance probability magnitude, using only the systematic gaged record at 520 $m^3 s^{-1}$. The combined paleoflood, historical, and gage records resulted in a much larger magnitudes for the 1% annual exceedance probability flood magnitude of 1320–1350 $m^3 s^{-1}$. The 0.1% annual exceedance probability magnitude is estimated at 770 $m^3 s^{-1}$ and 2100–2150 $m^3 s^{-1}$, respectively.

The hydroclimatic interpretation of this paleoflood record is complex, due to the discontinuity of the record. During the late Holocene, our flood data show three intervals differing in their flood regime: (1) 1280 ± 80 to 740 ± 90 years BP, with one extraordinary flood (>200 $m^3 s^{-1}$) about every 180 years; (2) 740 ± 90 to 200 ± 45 $^{14}C$ years BP, with one large flood per 80 years; and (3) 200 ± 45 $^{14}C$ years BP to AD1963, with one large flood per 7 years. Interval 2 represents large floods, probably related to the transition from a drier climate to the colder and probably wetter climate of the Little Ice Age (LIA). The third period relates to the end of the LIA and to a wetter period of the 19th and early 20th centuries in which more rainfall in the Kalahari and Namib Deserts and many historical floods were documented.

The presence of three distinct calcretes rich in calcified rhizoliths at one of the sites, two of which were dated by OSL to 13.2 ± 1.9 ka and 8.8 ± 1.0 ka, indicates, at least locally, higher moisture availability than in the current semiarid climate; the presence of denser vegetation can be associated with increased groundwater seepage and wetter climatic conditions.



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## 1. Introduction

Western Namibia is a desert crossed by east-west-oriented ephemeral rivers characterized by only a few floods per year. These floods are the main water resources for the ecology, wildlife, and people (Seely, 1978; Seely et al., 1981; Jacobson et al., 1995). The semi-arid Central Highland of Namibia at an altitude of up to 2000 m is the headwater and source of water for these ephemeral rivers which flow westward into the Atlantic Ocean (Fig. 1). The rivers in northern Namibia, which originate in more humid regions, experience more floods. The southern rivers and some of the northern rivers struggle through the Namib coastal desert, which is covered by sand and dunes, to the Atlantic Ocean. The dunes block the outlets of these rivers to the ocean, mainly during years with no floods or low flows (Seely and Sandelowsky, 1974), and force the channels of the southern rivers to the northwest (Fig. 1). Only large floods can remove these sand barriers, transporting large amounts of sand to the ocean (Stengel, 1964).

Crossing the coastal plain, the floodwaters of these ephemeral rivers recharge the sandy alluvial aquifers, which are the most important natural source of fresh water for the coastal population (e.g., Dahan et al., 2008; Morin et al., 2009). The pressure on water resources from increasing population and development is growing. However, little is known about the flood regime along these ephemeral rivers and their long-term potential contribution. Data on magnitude and frequency of floods and transmission losses are still scarce, giving rise to large uncertainties in the management of the limited water resources (Benito et al., 2010).

In the Kuiseb River basin of central Namibia (Fig. 1), studies have focused on flood hydrology and its associated transmission losses and groundwater recharge (Byers and Bruce, 1997; Hughes and Metzler, 1998; Botes et al., 2003; Schmitz, 2004; Lange, 2005; Dahan et al., 2008; Marx, 2009; Morin et al., 2009). These studies concluded that the largest floods (either in peak and/or duration) produce the largest aquifer recharge (Lange, 2005; Dahan et al., 2008; Marx, 2009; Morin et al., 2009), and that they occur primarily along the active channel, and not on the floodplain (Dahan et al., 2008; Morin et al., 2009). Therefore, any evaluation of sustainable water resources in the region requires a long-term record of floods and their potential drivers of change; namely climate and geomorphology, including changes in the alluvial fill, water inflow, and connectivity along the river. In the Swakop River, this connectivity has been affected by upstream damming (Fig. 1), which has significantly reduced the recharge of the alluvial aquifer downstream (Marx, 2009).

Studies of paleofloods at the Kuiseb River (Grodek et al., 2013) and Buffels River, South Africa (Benito et al., 2011) provide more detailed evidence for the paleohydrological-paleoclimatic reconstruction of the region during the last 1000 years.

The various proxies, locations, and methods provide diverse data and records of the late-Pleistocene and Holocene climate conditions in the region.

This paper focuses on identifying changes in flood regimes in the Swakop River, based on a detailed paleoflood study and interpretation of the reconstructed flood record, in the context of regional paleohydrologic and paleoclimatic variability. Optically Stimulated Luminescence (OSL) ages provide the chronology of the paleofloods older than the instrumental records in combination with documentary sources. The specific aims of this study are: (1) reconstruction of the long-term paleoflood record, using stratigraphic evidence from slackwater flood deposits with chronologies obtained by OSL ages; (2) combining all hydrological sources of non-systematic data (paleoflood and documentary information) and systematic data (gage record) to improve flood frequency

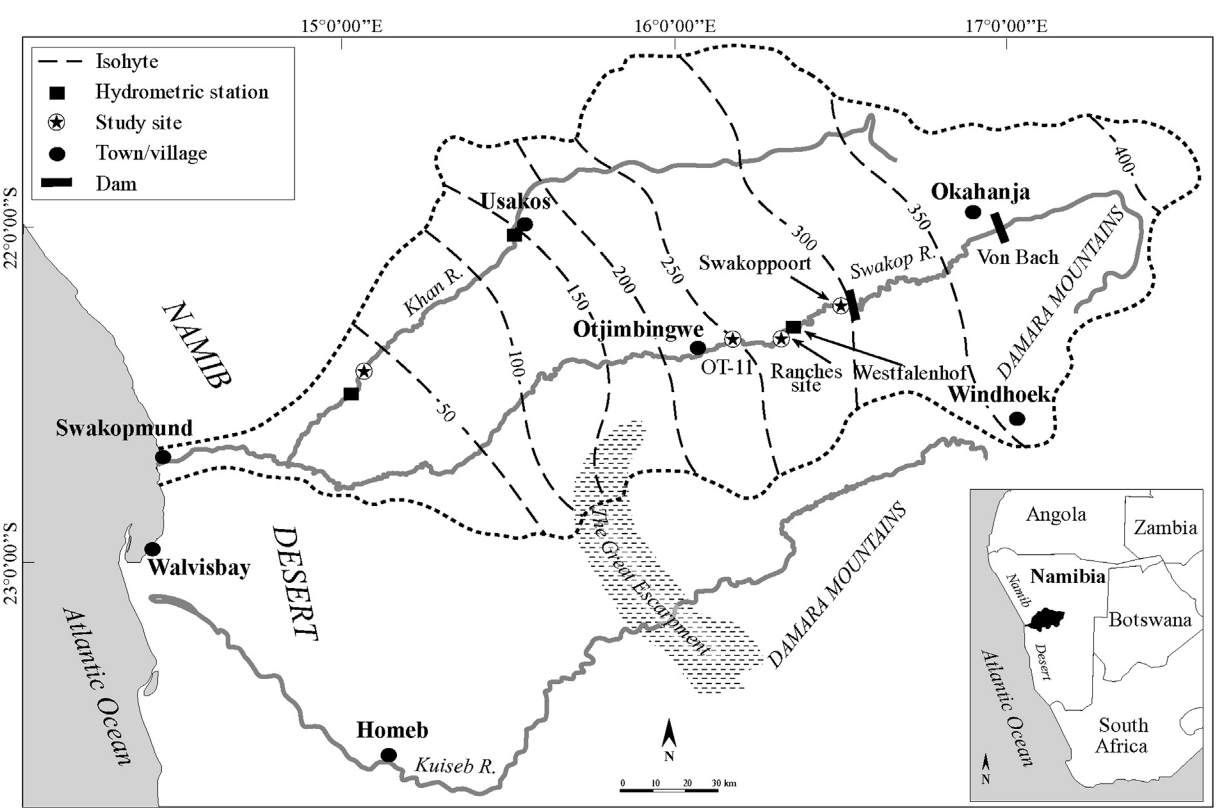


**Fig. 1.** Location map of the Swakop River drainage basin, including isohytes, towns, study sites, dams, hydrometric stations, and location of the study sites at the eastern margins of the Namib Desert.