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A spatio-temporal analysis of trends in rainfall from long term satellite rainfall products in the Sudano Sahelian zone of Nigeria

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ABSTRACT

Rainfall and its variability drive the rural economies across the Sudano-Sahelian zone of northern Nigeria, where drought strategies largely determine crop yields. The increasing scarcity of rain gauges in West Africa generally limits assessments of the degree and spatial extent of hardship arising from rainfall deficiency. However, the improved availability and robustness of satellite-based rainfall products since the early 1980s, offers an alternative source of rainfall data which is spatially, and often temporally, more complete than rain gauges. This research evaluates four satellite-based rainfall products for their ability to represent both long term rainfall trends such as recovery from decadal droughts, and trends in seasonal rainfall variables relevant to crop yield prediction. The Climate Hazards group Infrared Precipitation with Stations (CHIRPS) rainfall product at 5 km resolution, was observed to be consistently most representative of ground station rainfall across northern Nigeria over a 35-year period 1981–2015, followed by TARCAT. CHIRPS was found to give a good overall prediction of rainfall amounts at dekadal, monthly and seasonal time scales, and was therefore used in the study to represent the typical performance of satellite rainfall datasets. The CHIRPS-observed increase in growing season length since the 1970s and 80s drought decades, was accompanied by significant rainfall increases in the later part of the growing season, especially marked in northern and northeastern states. This is especially important for the main subsistence crops sorghum and millet as the risk of late drought impedes swelling of the grain, affecting dry weight production. The CHIRPS data also indicate a significant decrease in dry spells in the northwest and southern parts of the study area, which would have favourable outcomes for crop production in the densely populated rural hinterlands of the cities of Sokoto, Jos and Abuja. In view of the continued intra-and inter-annual rainfall variability across northern Nigeria, and amid rapid rural population growth recently, a return to the rainfall levels of the drought decades, would require informed response. The study suggests that satellite rainfall estimates can offer such information, especially since we observed high spatial variability in rainfall distributions and trends.

1. Introduction

The Sudano-Sahelian ecological zone of Sub-Saharan Africa at Latitude (12°–20 °N), is well known for its variable climate, where rainfall variability in the last three decades of the 20th century exceeded that in others parts of the world (Sanogo et al., 2015). The period 1931–1960 was considered to have above average rainfall, but an abrupt change occurred in the late 1960s, with up to 30% decline in average rainfall between 1961 and 1990 (Hulme, 1992; Fink et al., 2010). Severe droughts occurred during the 1970–1990 period (Nicholson, 2000), and those of 1972–1974 and 1983–1985 entailed severe food shortages, and loss of human life and livestock (Mortimore, 2000).

Northern Nigeria's climate is semi-arid, and rural livelihoods depend mainly on rain-fed agriculture (Hess et al., 1995; Tarhule and Woo, 1998), thus rainfall variability, which increases northwards, and changes in rainfall threaten the livelihoods of local people (Mortimore, 2000; Zhang et al., 2017). Timing of rainy season onset is important, as farmers make decisions about cropping and livestock movement which affect productivity, based on the first rains (Ingram et al., 2002). The major determinant of crop production is soil moisture, but the region's variable rainfall makes prediction of drought stress difficult. Drought stress during the seedling stage of the main cereal staples millet and sorghum results in reduced grain yield. For millet, drought just before

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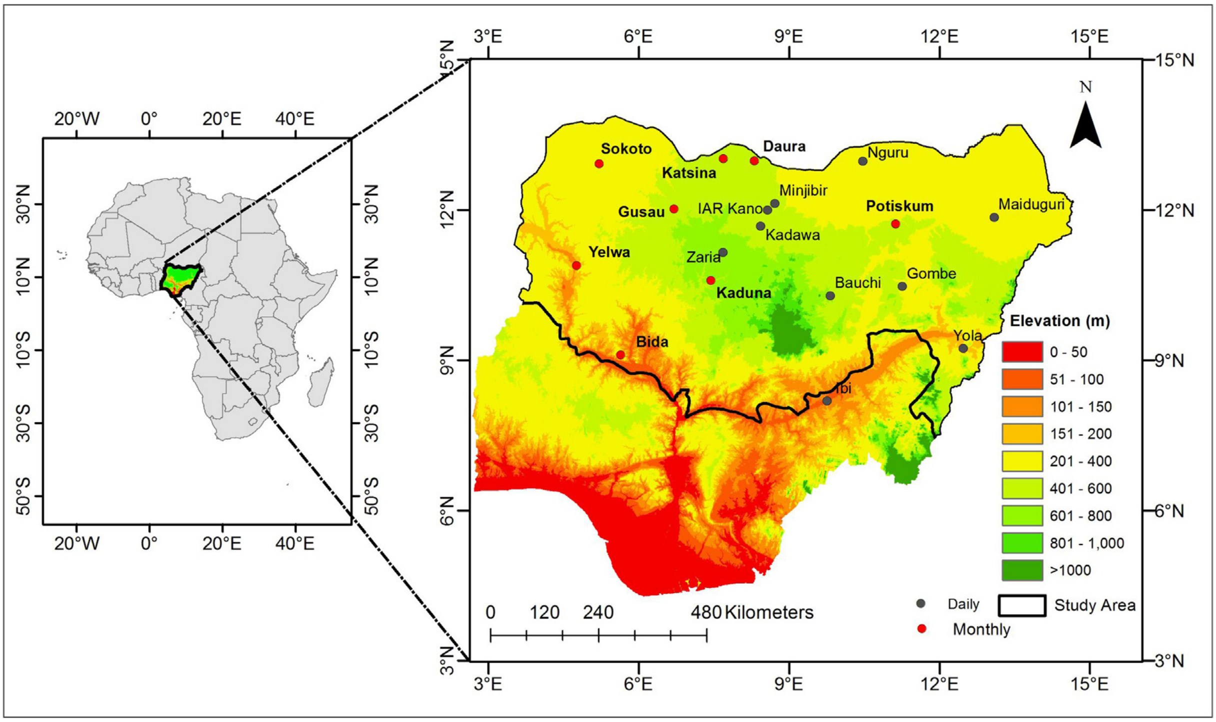

Fig. 1. Location of northern Nigerian states and weather station rain gauges. Grey circles denote availability of daily and dekadal data, and red circles denote the location of available monthly data (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

the flowering period may reduce yields by up to 70% (Seetharama et al., 1984). Sorghum in particular is sensitive to late season rainfall, as sorghum does not enter the high water use period during its life cycle until August. Thus in addition to total seasonal rainfall and timing of rainy season onset, other important rainfall variables include the number, timing and length of dry spells, and seasonal distribution of rainfall is also an important variable.

There are many accounts of rainfall trends in northern Nigeria (Buba, 2010; Hess et al., 1995; Olaniran, 1991, 1988; Mortimore, 2000; Tarhule and Woo, 1998; Tomlinson, 2010), mainly observing severe declines in the last decades of the 20th century, followed by a return to normal (Buba, 2010; Mortimore, 2000; Tomlinson, 2010). However, none provide a detailed study of the last 2 decades for different rainfall variables specific to crop production and rural livelihoods. For this, accurate rainfall data with high temporal, as well as spatial resolution is required.

Most of the rainfall in Africa is formed by convective clouds, thus rainfall amount can vary over a few tens of km (Nicholson, 2000). However, the spatial distribution of rain gauge stations in West Africa is very sparse and these were significantly reduced over the last 3–4 decades (Sanogo et al., 2015). For example the number of gauges returning rainfall records in northern Kaduna state (now Katsina state) diminished from about 50 in 1941–70 to only 12 by 1999 (Tomlinson, 2010).

Satellite based precipitation estimates provide an alternative to sparse, traditional gauge-based rainfall measurements. They are at continental and global scale and have high spatial and -temporal resolution. Thus they provide timely, repetitive and cost effective information about rainfall at different time scales from daily to annual. It is therefore necessary to assess the accuracy of different satellite based rainfall products compared to gauge rainfall, before they can be considered operational for local crop production forecasting and rural productivity assessments. A few previous studies have evaluated satellite-based rainfall products at continental scale: for West Africa (Sanogo et al., 2015), and for three different river basins in Africa (Thiemig et al., 2012). Also there are some studies at country level including Burkina Faso (Dembélé and Zwart, 2016), Ethiopia (Bayissa et al., 2017) and Mozambique (Toté et al., 2015).

However, evaluations of satellite based rainfall products show large differences in algorithm performance depending on location, local climate, season and topography (Maidment et al., 2013; Toté et al., 2015). Also choice of the best rainfall product depends on the specific application. For drought monitoring studies, accuracy of low rainfall is the main requirement, and for hydrological and flood forecasting application, accuracy of high rainfall events is crucial (Toté et al., 2015).

Almost all studies of rainfall in northern Nigeria report great spatial variation in rainfall amounts and trends, with large differences in nearby areas, and many conflict with other studies (Buba, 2010; Mortimore, 2000; Tomlinson, 2010) for the same regions. Additionally, previous studies have been confined to data from a few climate stations, and are therefore spatially incomplete. In many cases satellite-based observations appear to conflict with farmers' perceptions of rainfall trends and its effects on their lives (West et al., 2008). This study aims to evaluate the available sources of both spatial and temporal rainfall data over recent decades in northern Nigeria, and to assess impacts on the rural landscape and agricultural economy.

The specific objectives of this study are: 1) to compare temporal trends in rainfall data from ground stations at daily, dekadal, monthly and annual time scales, with satellite-based estimates which use a combination of thermal infra-red and radar images, and ground station data, as satellite rainfall estimates can increase the spatial coverage if proved to be reliable; 2) to evaluate satellite rainfall products for retrieval of seasonal rainfall variables; 3) to analyse temporal trends over a 30-year period (1984–2013) from gauge-based rainfall variables; and 4) to analyse both spatial and temporal variability over the same 30-year period (1984–2013) using satellite derived rainfall variables.

2. Study area

The study area covers the Sudano-Sahelian savanna ecological zone of northern Nigeria between latitude 8°–16 °N and longitude 1°–17 °E. This zone covers the northern states and the Federal Capital Territory