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Spatial variability of daily summer rainfall at a local-scale in a mountainous terrain and humid tropical region

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ABSTRACT

The authors study the spatial variability of daily rainfall in a mountainous terrain and tropical humid region within a grid of 6 km × 6 km using daily rainfall data from 22 non-recording rain gauges over a period of 39 days. Results indicate that (1) the daily coefficient of variation varied from 15% to 53%, and (2) among all, five of the rain gauge locations consistently gave estimates of the spatial daily mean rainfall within root mean square error of 20%, ten locations gave estimates with root mean square errors ranging from 20% to 30%, and the remaining seven locations gave estimates with root mean square error ranging from 30% to 41%. These levels of errors must be acknowledged when using single rain gauges to estimate local-scale spatial means at the daily scale. This also indicates that there are temporally stable rain gauge locations that give consistently lower errors in spatial mean estimates. Such short-term field campaigns can be used to identify time stable rain gauge locations for rain gauge network design.

1. Introduction

Traditionally rainfall is measured using a rain gauge, a sensor that accurately measures the actual amount of rainfall that falls over a small area, a few squared centimeters. Rain gauges are often less-densely deployed and/or less consistently maintained, resulting in spatial and temporal gaps. During recent years, the increased space–time resolution and near-global availability of satellite products have made them a viable alternative to rain gauge data for hydrological applications. However, satellite rainfall estimates are known to contain errors arising from several sources. Quantification and minimization of these errors is important to enhance the utility of satellite rainfall products. This requires comparison against independent, high-quality, rainfall data at the same resolution (e.g., Krajewski et al., 2000; Habib and Krajewski, 2002; Gebremichael et al., 2003, 2005).

Such data often come from experimental, highly-dense rain gauge network and/or ground-based radar facilities, often referred to as 'ground validation sites'. Errors in satellite rainfall products vary with precipitation processes (Berg et al., 2006; Gebremichael et al., 2003, 2005), and recognition of this fact has led to the establishment of a number of ground validation sites in the developed world for economic reasons, and over relatively flat regions for ease of establishing such sites (Smith et al., 2007). In mountainous regions, in addition to the stochastic nature of rainfall, the rainfall pattern may be influenced by irregular topography, making the task of establishing ground validation sites more difficult.

In several developing countries, and particularly in mountainous regions, such ground validation sites do not exist. However, there are sparse rain gauge networks available in such regions. Can a single rain gauge located within a grid that approximately matches the resolution of high-resolution satellite rainfall products (i.e. 4 km to 8 km × 4 km to 8 km) be used to give estimate of the error in these satellite products, say at a daily time scale? What would be the error in using data from single rain gauges for estimating spatial means? Is there a single rain gauge location that consistently represents the spatial mean? To answer

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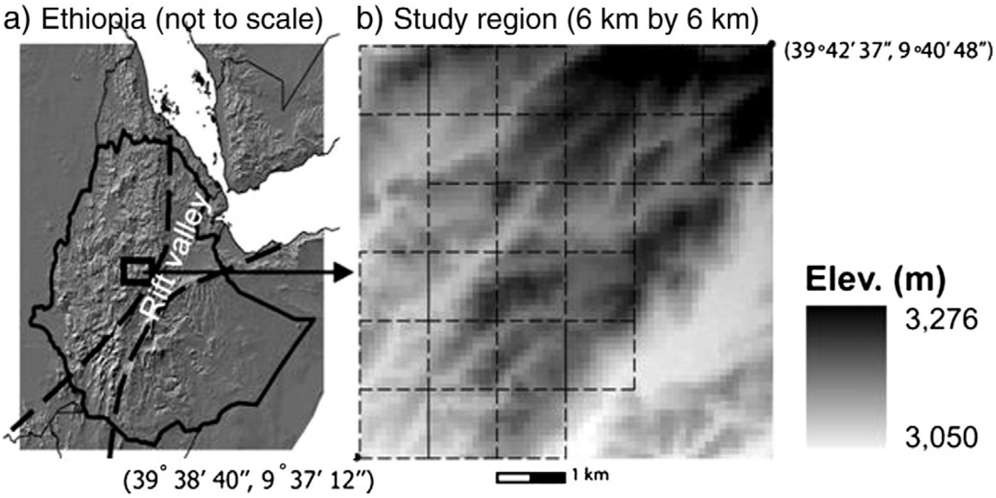

Fig. 1. (a) Relief-shaded map of Ethiopia showing the location of the study region with respect to the rift valley; (b) the digital elevation map of the 6 km by 6 km study region.

these questions, it is necessary to understand the spatial distribution of daily rainfall within such size areas. The purpose of this study is to investigate the spatial variability of daily rainfall within a grid of 6 km × 6 km in a mountainous and tropical humid region in Ethiopian highland.

2. Study region

HEXB'08 (Hydrological EXperiment in Blue Nile; Bitew et al., 2009) was a rainfall experiment conducted by the University of Connecticut in collaboration with Addis Ababa University and Amhara Regional Agricultural Research Institute in Ethiopia. It was funded by the National Science Foundation. An area of 6 km by 6 km within the Beressa watershed was the focus of the local-scale rainfall measurement during HEXB'08. Fig. 1 shows the digital elevation map of the area from the U.S. Geological Survey (USGS) at 30 m resolution. There is a considerable variation in elevation, ranging from 3050 m to 3276 m, over this small area. Geologically, it is part of a huge land mass that covers more than 300,000 km^2 in central Ethiopian highland. The high altitude and mountainous nature of the area is associated with the uplift during the rifting process and a series of volcanisms. The regional climate is classified as tropical humid with an average annual rainfall of 1100 mm. Most of the annual rainfall comes from summer monsoon. Major rain producing systems during summer monsoon are: the northward migration of the ITCZ; development and persistence of the Arabian and the Sudan thermal lows along 20° N latitude; development of quasi-permanent high-pressure systems over the south Atlantic and south Indian oceans; development of the tropical easterly jet and its persistence; and the generation of the low-level Somali jet, which enhances low level southwesterly flow (Seleshi and Zanke, 2004).

Initially, we installed rain gauges every kilometer within the 6 km by 6 km area, but we lost some of them during the experimental period. Fig. 2 shows the layout of the resulting network of 22 rain gauges. The non-recording rain gauges used were the "Tru-Chek®" plastic rain gauges manufactured by the Forestry Suppliers. The gauges have scales permanently marked on the front sides. We mounted each gauge vertically on a wooden pole at a height of 2 m above the ground. A typical rain gauge installation is shown in Fig. 3. Our research group and trained local research assistants took readings off each rain gauge, every morning from 7 am to 8 am, for the period of July 2 to August 9, 2008. This is the major rainy period in the region; there were 37 rainy days during the 39-day experimental period.

3. Method of analysis

We used coefficient of variation to measure spatial variability. A large coefficient of variation for a rainfall event indicates that the spatial variability is large.

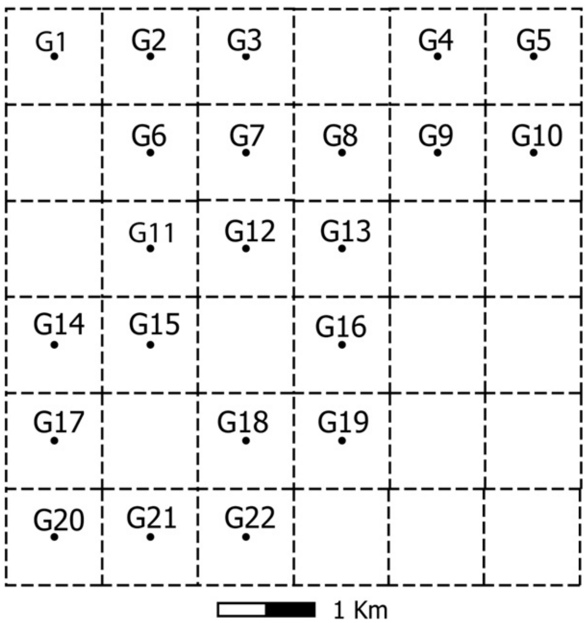

Fig. 2. Location of the 22 rain gauges marked with GX. The 1 km by 1 km grid is marked with dashed lines.