Physics and Chemistry of the Earth xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Validation of remotely sensed rainfall over major climatic regions in Northeast Tanzania

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ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Satellite rainfall estimates
Pangani
TRMM
RFE
Data scarcity

ABSTRACT

Increase in population has resulted in pressure for more land and water use for food security in Northeast Tanzania. This calls for proper understanding of spatial-temporal variations of quality and quantity of water to ensure sustainable management. The number of hydro-meteorological stations such as rainfall stations and flow measuring stations has not increased and even the functioning of the existing ones is deteriorating. Satellite rainfall estimates (SRE) are being used widely in place of gauge observations or to supplement gauge observations. However, rigorous validation is necessary to have some level of confidence in using the satellite products for different applications. This paper discusses the results of application of SRE over a data scarce tropical complex region in Northeast Tanzania. We selected river catchments found in two different climatological zones: the inland region mountains (i.e. Kikuletwa and Ruvu basins) and the coastal region mountains (i.e. Mkomazi, Luengera and Zigi basins), characterized by semi arid, sub-humid to humid tropical climate. Thus, the validation sites were ideal for testing the different SRE products. In this study, we evaluated two gauge corrected high resolution SRE products which combine both infrared and passive-microwave estimates; the National Oceanographic and Atmospheric Administration Climate Prediction Center (NOAA-CPC) African Rainfall Estimation (RFE2) and the Tropical Rainfall Measuring Mission product 3B42 (TRMM-3B42) using station network.

The accuracy of the products was evaluated through a comparison with available gauge data. The comparison was made on pair-wise (point to pixel) and sub-basin level with the reproduction of rainfall volume, rainfall intensity and consistency of rain and no-rain days. The SRE products performed reasonably well over both regions in detecting the occurrence of rainfall. The underestimation was mainly ascribed to topology and the coastal effect. Whereas, the overestimation was mainly ascribed to evaporation of rainfall in the dry atmosphere under the cloud base. Local calibration of satellite-derived rainfall estimates and merging of satellite estimates with locally available rain-gauge observations are some of the approaches that could be employed to alleviate these problems. Although, the products did not show strong correlation to the observed rainfall over the complex tropical mountainous catchments considered, they have high potential to augment gauge observations in data sparse basins.

1. Introduction

Climate related hazards such as droughts and floods are increasing in Tanzania (URT, 2012), all of which have serious water resources implications. There is therefore a need to strengthen the tools which can be used to shed more light on what is happening both at spatial-temporal scale in terms of water quantity and even quality.

Hydrological models may be used to forecast what will happen under different scenarios of land use/cover and precipitation but the applicability is largely limited by lack of data especially in developing countries. Satellite remote sensing now has the potential to provide extensive coverage of key variables such as precipitation (Smith et al., 1996; Sturdevant-Rees et al., 2001), soil moisture (Sano et al., 1998) and flooding extent (Townsend and Foster, 2002), as well as parameters such as vegetation cover (Nemani et al., 1993), vegetation change (Nemani et al., 1996) and surface imperviousness (Slonecker et al., 2001) that are important inputs to modern hydrological models. The range and extent of these inputs would have been impractical to obtain through traditional, terrestrial, data collection techniques (Entekhabi et al., 1999).

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http://dx.doi.org/10.1016/j.pce.2013.09.013

The spatial variability of rainfall is often identified as the major source of error in investigations of rainfall–runoff processes and hydrological modeling (O'Loughlin et al., 1996; Syed et al., 2003). However, in Tanzania the extent of the ground-based rainfall network is not adequate to capture all the spatial rainfall variability. Many data collection programs have been abandoned for socio-economic or political reasons, resulting in both spatial and temporal gaps in valuable data time series. Remote sensing offers extremely valuable opportunities to not only fill the gaps, but also to extend the point measurements into spatio-temporal estimates of rainfall. The retrieval of rain rate from satellite data is one of the major research fields in satellite meteorology at the moment and different research groups are trying to co-ordinate those efforts on an international basis. Many of those satellite rainfall estimate (SRE) products are freely available through the internet but in many parts of Africa, there has been very little validation work (see Laurent et al., 1998; Grimes et al., 1999; Nicholson et al., 2003a,b; Thorne et al., 2001; Ali et al., 2005; Hughes, 2006; Dinku et al., 2007, 2008).

In the present study, two SRE products: the National Oceanographic and Atmospheric Administration Climate Prediction Center (NOAA-CPC) African rainfall estimation (RFE2) and the Tropical Rainfall Measuring Mission product 3B42 (TRMM-3B42) are applied and validated over the major climatic regions in Northeast Tanzania. It is essential to quantify direct use of these products in flood forecasting and hydrological modeling.

2. Study area

Northeast Tanzania comprises three administrative regions of Tanga, Kilimanjaro and Arusha, which fall within three hydrological basins: the large Pangani, medium Umba and small Zigi (Fig. 1). The Pangani River Basin covers an area of about 43,600 km^2 extending from the northern mountains of Kilimanjaro and Meru through the central Maasai Steppes and Usambara Mountains to the Indian Ocean. The surface water resources of Pangani are further subdivided by the *Nyumba ya Mungu* Reservoir into two main systems, the *upstream* and *downstream* water resource systems. The upstream system comprises the eastern Ruvu river, which drains the area between Mount Kilimanjaro and the North Pare Mountains, and the western Kikuletwa river, which drains the areas around Mount Kilimanjaro and Mount Meru. The downstream system comprises the Mkomazi river, which drains the South Pare Mountains and the Luengera river which drains the catchment area between the western and eastern Usambara Mountains. The rivers draining mountains in the coastal region (Umba, Sigi, Luengera, Mkomazi and Lower Pangani) exhibit different multi-year pattern of variability from that of rivers draining the northern inland region mountains (Kikuletwa, Ruvu and Upper Pangani).

The high altitude slopes above the forest line on Mt. Meru and Mt. Kilimanjaro have an Afro-Alpine climate and receive in excess of 2500 mm of rainfall per year. The middle slopes of these mountains, and the Pare and Usambara Mountains are characterized by a humid to sub-humid tropical climate. Forest reserves, grasslands and bushlands cover the mountain slopes and no agricultural activities are entertained within reserve areas. Mean annual rainfall increases in a southerly direction along the mountain range, and varies from about 650 mm/year in the North and South Pare Mountains, to 800 mm/year in the Western Usambara Mountains, and 2000 mm/year in the Eastern Usambara Mountains. The lower Mkomazi catchment and the lower Pangani catchment have a sub-humid to semi-arid climate. These areas are not forested although they have a high agricultural potential. Cash crops such as tea and some coffee growing is practiced. The central and western parts of the Basin have a semi-arid to arid climate. Rainfall varies between 300 and 600 mm/year. The area is covered in dry woodlands and thorn bushveld, and has marginal agricultural potential (mainly sisal). From these areas, five catchments were selected to be used in the comparison of satellite and terrestrial precipitation estimates; Kikuletwa (6765 km^2), Ruvu (6065 km^2), Mkomazi (3902 km^2), Luengera (1310 km^2) and Zigi (1068 km^2) (Fig. 1).

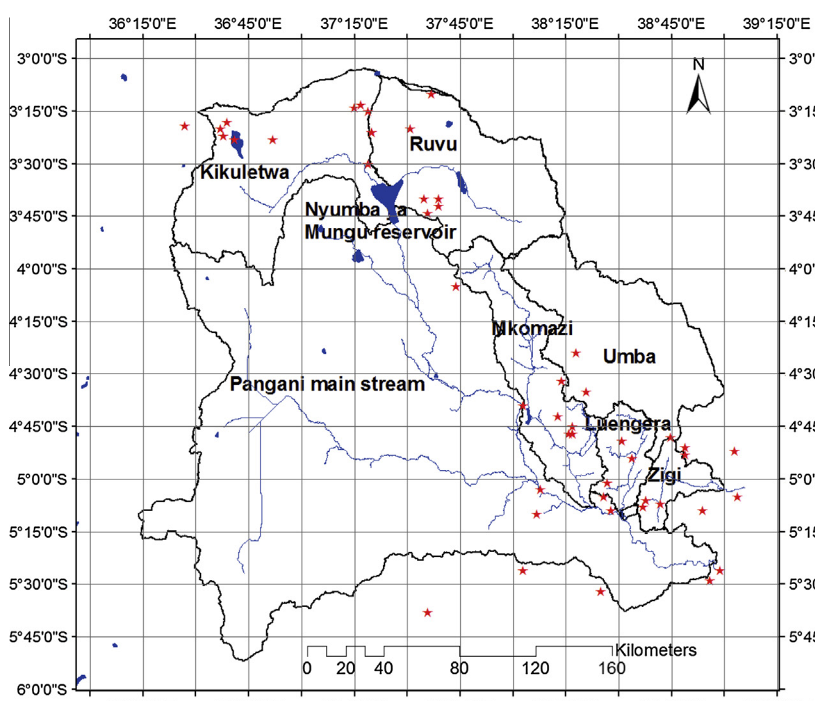

Fig. 1. Location and hydro-meteorological network of the basins in Northeast Tanzania with a 0.25° × 0.25° grid overlay.