

Evaluation of TRMM satellite-based precipitation indexes for flood forecasting over Riyadh City, Saudi Arabia



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SUMMARY

Floods are among the most common disasters harming humanity. In particular, flash floods cause hazards to life, property and any type of structures. Arid and semi-arid regions are equally prone to flash floods like regions with abundant rainfall. Despite rareness of intensive and frequent rainfall events over Kingdom of Saudi Arabia (KSA); an arid/semi-arid region, occasional flash floods occur and result in large amounts of damaging surface runoff. The flooding of 16 November, 2013 in Riyadh; the capital city of KSA, resulted in killing some people and led to much property damage. The Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) Real Time (RT) data (3B42RT) are used herein for flash flood forecasting. 3B42RT detected high-intensity rainfall events matching with the distribution of observed floods over KSA. A flood early warning system based on exceedance of threshold limits on 3B42RT data is proposed for Riyadh. Three different indexes: Constant Threshold (CT), Cumulative Distribution Functions (CDF) and Riyadh Flood Precipitation Index (RFPI) are developed using 14-year 3B42RT data from 2000 to 2013. RFPI and CDF with 90% captured the three major flooding events that occurred in February 2005, May 2010 and November 2013 in Riyadh. CT with 3 mm/h intensity indicated the 2013 flooding, but missed those of 2005 and 2010. The methodology implemented herein is a first-step simple and accurate way for flash flood forecasting over Riyadh. The simplicity of the methodology enables its applicability for the TRMM follow-on missions like Global Precipitation Measurement (GPM) mission.

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1. Introduction

Among various natural disasters, floods have been the most common one (World Disasters Report, 2003). Moreover, flash floods are among the mostly faced and the most deadly (Hapuarachchi et al., 2011; Jonkman and Kelman, 2005) despite their limited affected area (Borga et al., 2014) and being one of the most challenging topics for the research community (Alfieri et al., 2011). Hapuarachchi et al. (2011) tied the driving mechanisms of flash floods either to excessive rainfall or to dam failure; they mentioned the rareness of dam failures and focused on excessive rainfall.

Regions with plentiful rainfall, as well as arid and semi-arid regions, are equally vulnerable to flash floods. Actually, the strongest convective storms are detected in semi-arid regions (Zipser et al., 2006). Recent flood events that occurred in Riyadh,

Jeddah and Abha Regions among others in Kingdom of Saudi Arabia (KSA) reflect flash flood risks in arid/semi-arid regions (Fig. 1).

The high fatalities and damages of flash floods arise from the fact that they occur rapidly without enabling time to take mitigation effects. Severity of the damage increases in developing countries where generally warning systems are missing and infrastructures are inadequate (Pombo and de Oliveira, 2015). Developing flood warning systems have been reported in literature as the most effective way to reduce loss of life and property damage (Negri et al., 2005). The advances and criteria in flash flood occurrence methods were reviewed and summarized in Hapuarachchi et al. (2011) and Alfieri and Thielen (2012) in three main categories: Flood Susceptibility Assessment (FSA), Rainfall Comparison (RC) and Flow Comparison (FC). They mentioned that RC indicates a good tradeoff between simplicity and good estimates by requiring just Quantitative Precipitation Estimates (QPE).

As mentioned in Negri et al. (2005), during the flooding events rainfall measurements from ground-based gauging stations can be problematic, since they can be damaged or data transmission may not be possible. These can be minimized by optimal sensor

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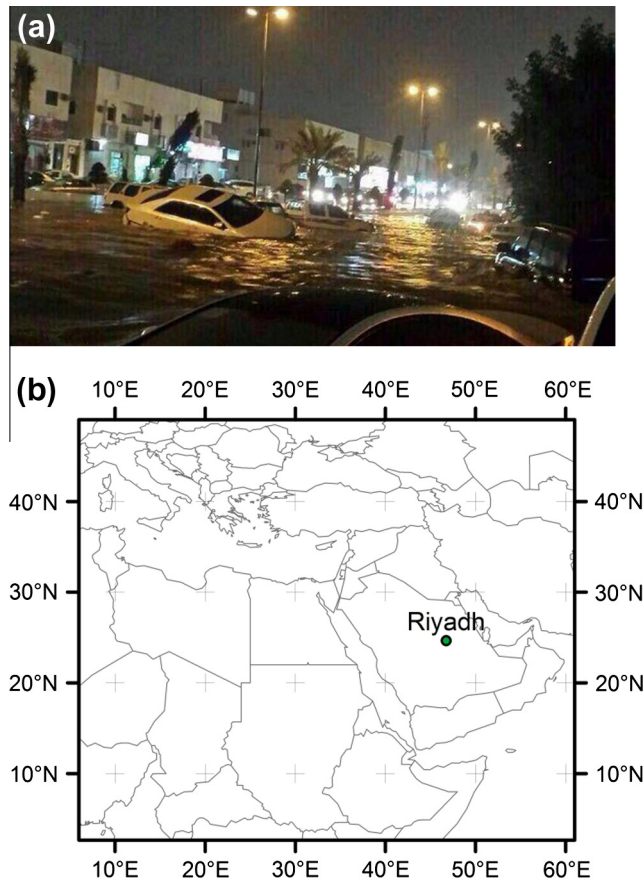


Fig. 1. Photos of flood on 16 November, 2013 in Riyadh (a) Source: <http://english.alarabiya.net/en/News/middle-east/2013/11/17/Video-Saudi-capital-flooded-with-heavy-rains.html>, location of Riyadh in KSA (b).

selection based on the physiographic condition of the region and provision of redundant telecommunication systems. However, Borga et al. (2014) mentioned the inadequacy of rain gauge networks in reproducing the high spatial variability. Thus, the use of remote sensing either from ground-based radar or satellite-based systems is gaining importance (Wardah et al., 2008) and is being widely used. However, both ground-based radar and satellite-based systems need to be validated. This validation can only be possible by ground observations, which are mainly recorded by gauges. An efficient way for flood monitoring can be achieved by combining all information from gauges, ground radars and satellite systems.

Especially, space-borne sensors gave researchers opportunities for developing new ways of flood warning systems to monitor and detect the extreme rain events during which the conventional systems may be obsolete. In this context, multi satellite imagery acquired and processed in real time can provide near real time rainfall fluxes at relatively fine spatiotemporal scales (kilometres to tens of kilometers and 30-min to 3-h) (Hong et al., 2010). Improvements in the hardware and the algorithm developments enabled the implementation of satellite-based flood warning systems supplementing ground-based observations and provide uninterrupted monitoring of extreme events (Asante et al., 2007; Hong et al., 2007). Extreme flooding events and sub-daily variations of rainfall can be tracked by multi-satellite images acquired and processed in real time. Fig. 2 shows the heavy rain areas on 12 March, 2014 in Middle East, North Africa and Southern Europe. It is believed that satellite-based precipitation products can decrease mortality by improving and enabling timely warning (Hong et al.,

2007). Borga et al. (2014) expressed that detection of precipitation by remote sensing and numerical weather predictions became major component in flood warning systems. Early warning systems combining satellite observations, ground radars, in situ gauges and numerical weather prediction systems have been mentioned in the literature (Seyyedi, 2010; Zhang, 2012; Coning, 2013; Sene, 2013). However, no such system is operationally working over KSA at present.

In this study, different flood indexes based on TRMM satellite-derived precipitation rain rates are evaluated for forecasting of flooding events occurring in an arid/semiarid region in Middle East; i.e. KSA. Thus, the objective of the current article is to evaluate the capability of TRMM-based indexes in identifying the flooding events. Section 2 provides information about the study area and the data set used. Section 3 explains the methodology and the derivation of indexes. Section 4 summarizes the results and Section 5 concludes the study.

2. Study area and data sets

2.1. Study area

The capital city of KSA; Riyadh (Fig. 1b), is located in the centre of the Arabian Peninsula linking Asia to Africa (Subyani, 2010) and constitutes the study area. Riyadh's climate is classified as arid with summer months air temperatures reaching above 45 °C with no rainfall (PME, 2015). The number of rainy days in a year is on average 16, with an annual average total rain depth of 95 mm, which is mostly seen during November–April. Despite being scarce, high rainfall intensities can be observed (Almazroui, 2011a). Alamri (2011) mentioned that flood-based events hold 65% of the total fatalities in various disastrous over KSA. Impervious land use around the city reduces infiltration and increase runoff coefficients, leading to flash floods. Population growth with increasing constructions will further increase surface runoff amounts. Furthermore, in Almazroui (2011b) it is indicated that little precipitation in KSA can cause flash floods since the soil does not soak up water very easily.

Despite the high fatalities, it is extremely hard, if not impossible, to find information about flood events that occurred in KSA. Past flood events gathered from the International Disaster Database (TIDD, 2015) are presented in Table 1. Two more flooding events were obtained from the internet: one on 3 May, 2010 and another in February 2005 for which the exact date could not be found.

2.2. TRMM 3B42 RT

The Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) intended to provide a “best” estimate of quasi-global precipitation from the wide variety of modern satellite-borne precipitation sensors at relatively fine scales ($0.25^\circ \times 0.25^\circ$ and 3 h) in both real and post-real time to accommodate a wide range for researchers. 6–9 h after observation, Real Time (RT) data can be obtained and 15 days after the end of the month, research products are released (Huffman et al., 2007). The latter is known as 3B42, while the former is called 3B42RT.

Almazroui (2011b) concluded that TRMM results are good enough to be used in a variety of water-related applications over KSA where the rainfall climatology during 1998–2009 is determined based on 3B42. In addition, the high performance of TRMM 3B42 over KSA are mentioned in Kheimi and Gutub (2014). Although 3B42 data was tested over KSA before, to our present knowledge, this is the first time 3B42RT data are used. As the

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