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Journal of Arid Environments 67 (2006) 607–628

Journal of Arid Environments

www.elsevier.com/locate/jnlabr/yjare

Evidence of urban-induced precipitation variability in arid climate regimes

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Received 17 May 2005; received in revised form 25 January 2006; accepted 9 March 2006
Available online 24 May 2006

Abstract

The study employs a 108-year precipitation historical data record, global climate observing network observations and satellite data to identify possible anomalies in rainfall in and around two major arid urban areas, Phoenix, Arizona and Riyadh, Saudi Arabia. The analysis reveals that during the monsoon season, locations in northeastern suburbs and exurbs of the Phoenix metropolitan area have experienced statistically significant increases in mean precipitation of 12–14% from a pre-urban (1895–1949) to post-urban (1950–2003) period. Further analysis of satellite-based rainfall rates suggests the existence of the anomaly region (AR) over a 7-year period. The anomaly cannot simply be attributed to maximum topographic relief and is hypothesized to be related to urban-topographic interactions and possibly irrigation moisture. Temperature records suggest that Riyadh has experienced an adjustment in mean temperature in response to the growth of urban surfaces (e.g. the so-called urban heat island effect). While ground-based precipitation records also indicate an upward trend in mean and total precipitation in and around Riyadh in the last 10–15 years, it is difficult to attribute the increase to urbanization because other less urbanized stations in Saudi Arabia also show a similar increase. Recent satellite-based precipitation estimates indicate an AR 50–100 km north of Riyadh, but this study is not robust enough to conclusively link it to urbanization although certain climate-regime attributes suggests that it might be.

Keywords: Urban; Precipitation; Climate; Phoenix; Middle East; Anthropogenic

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doi:10.1016/j.jaridenv.2006.03.022

1. Introduction

Water is essential to life in the Earth system. The water cycle components that sustain life are becoming more scarce and polluted. The most recent (1999–2004) drought experienced in the southwestern United States is the seventh worst in the approximately 500-year proxy tree-ring record (Piechota et al., 2004). As a result, many regions contemplated "drought emergencies" in which severe water restrictions are implemented. Though large-scale forcing likely controls drought processes (Hidalgo, 2004), there is increasing evidence that anthropogenic or "human-related" activities can significantly alter precipitation processes. Urbanization is an example of anthropogenic forcing. Recent studies (Bornstein and Lin, 2000; Orville et al., 2001; Dixon and Mote, 2003; Shepherd and Burian, 2003; Inoue and Kimura, 2004; Molders and Olson, 2004; Burian and Shepherd, 2005; Shepherd, 2005) continue to provide evidence that urban environments can modify or induce precipitation under a specific set of conditions. Results of these recent studies are consistent with previous historical work in this research area (Changnon et al., 1981; Huff, 1986).

Arid and semi-arid regions of the southwestern United States and other parts of the world are rapidly developing and placing greater demands on the environmental system. In the past 50 years, Phoenix has expanded from a predominantly agricultural center to an urbanized region with extent 700% larger than its size in the middle of the twentieth century (Rex, 2000). Riyadh's population grew from about a half million people in 1972 to almost 2 million by 2000. Saudi Arabia experienced urbanization later than many other countries; in the early 1970s its urban-rural ratio was still about 1:3. By 1990, the ratio had reversed to about 3:1. In the mid-1970s, Riyadh's population was increasing by about 10% a year. Irrigation also significantly increased between 1972 and 1990 (Metz, 1993) southeast of Riyadh.

Fig. 1 is an LANDSAT image depicting the rapid growth of Phoenix over the past few decades. Fig. 2 is a combined LANDSAT and advanced spaceborne thermal emission and reflection radiometer (ASTER) image depicting the rapid urban growth of Riyadh, Saudi

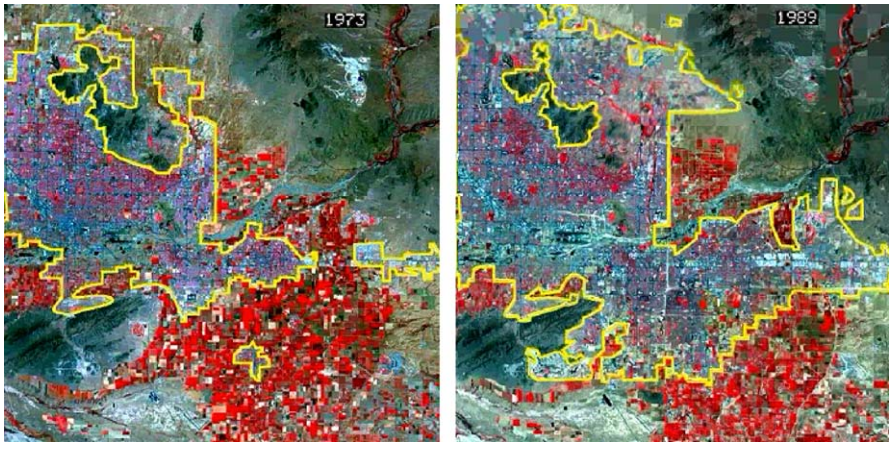

Fig. 1. LANDSAT images illustrating the growth of the Phoenix metropolitan area from 1973 to 1989. The yellow outline encompasses the urban region. Red colours are crops or vegetation.