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Influence of land use/land cover (LULC) changes on atmospheric dynamics over the arid region of Rajasthan state, India

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A B S T R A C T

The present study examines the long-term effects of land use/land cover (LULC) changes in Rajasthan state, India on land-atmosphere fluxes and, possibly in precipitation and aerosol loading. By comparing the satellite observations from Landsat MSS (1972–73) and IRS-P6 AWiFS (2006–07) considerable LULC changes are observed, an increase in crop-land and vegetated areas of ~57% in the eastern and ~68% in the western Rajasthan. The increase in agriculture intensification from irrigation activities after the construction of the Indira Gandhi canal (IGC) seems to affect the land-atmosphere fluxes, i.e. increase in atmospheric humidity and latent heat and reduction in sensible heat. On the other hand, the multi-decadal variability (1951–2007) in annual rainfall amount and total number of rainy days reveals significant year-to-year fluctuations, exhibiting a slight increasing trend over arid western Rajasthan. However, the overall analysis shows that the variability in precipitation is much more influenced by the general monsoonal circulation (i.e. meteorological dynamics and intensity of the monsoon) and partly can be associated with local phenomena, such as LULC changes and modifications in land-atmosphere fluxes. Similarly to precipitation, the long-term (1979–2008) aerosol index (AI) variations over the region seem to be affected by atmospheric and meteorological dynamics and not by LULC changes.

1. Introduction

Land use and land cover changes (LULC) are linked to global climate change and several other environmental issues concerning land-atmosphere interactions, such as thermal and latent heat fluxes, evapotranspiration and the exchange of greenhouse gases from plants and soil into the atmosphere (IPCC, 2007). The land surface is an important component of the Earth's climate system as a source of moisture and energy for the atmosphere and, therefore, any perturbation in land-surface properties can cause significant changes in the boundary-layer dynamics (Baidya Roy et al., 2003). On the other hand, changes in LC and crop type may affect the precipitation and hydrological cycle through the partitioning of the incoming solar radiation into turbulent sensible and latent heat fluxes (Bookhagen and Burbank, 2006; Prasad et al., 2007; Sarkar et al., 2007a). Therefore, numerous studies have focused on the effects of LULC changes in atmospheric properties and processes, such as boundary layer dynamics (Niyogi et al., 1999), convection (Pielke, 2001), mesoscale circulations (Baidya Roy and Avissar, 2002), cloudiness and cloud properties (Ray et al., 2003) and precipitation (Douglas et al., 2009; Marshall et al., 2004; Pielke et al., 2007; Ray et al., 2006). Thus, on the one hand global climate change affects terrestrial ecosystems and, from the other, these ecosystems can also affect the regional climate by impacting net radiation and surface heat fluxes (Chase et al., 2000; Foley et al., 2003; Pielke et al., 2002).

As a consequence, the linkage between LULC changes and perturbation in atmospheric processes has attracted the attention of the scientific community. Fall et al. (2010) suggested that LULC changes produced a significant cooling effect over parts of the United States and anthropogenic activities were responsible for the modification in the urban precipitation, primarily due to re-distribution of the local energy budget by expansion of the urban areas. Baidya Roy et al. (2003) studied the impact of LULC change in United States and found reduction in precipitation mainly due to changes in the large-scale moisture advection patterns. Kaufman et al. (2007) also established the impact of urbanization in the

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Pearl River Delta, China and found decrease in rainfall due to increase in urban areas, primarily affected by changes in surface hydrology that extend beyond the urban heat island effect and energy-related emissions (Arnfield, 2003). Moreover, the irrigation impacts on land-surface fluxes, atmospheric circulation and climate have been examined (e.g. Kueppers and Snyder, 2012; Zhu et al., 2011).

Furthermore, several modeling studies have been carried out to study the impact of LULC changes on regional climate over Indian sub-continent (De Rosnay et al., 2003; Douglas et al., 2006; Lohar and Pal, 1995; Subash et al., 2011) suggesting that irrigation alters water-vapor and energy fluxes on regional and sub-continental scales. Sarkar and Kafatos (2004) using monthly Normalized Difference Vegetation Index (NDVI) data for 18 years (1982–2000) over India found a significant linkage between rainfall amount and land-surface temperature with spatial and temporal variations of vegetation. Recent modeling investigations suggested that major modifications of the biosphere in the Indian sub-continent influence monsoon circulation and rainfall by altering the surface energy balance, the planetary boundary layer motion fields, the moisture convergence and the hydrological cycle (Douglas et al., 2009), also suggesting that the Indian monsoon was significantly weakened by both an increase in surface albedo and by a reduction in surface roughness.

India's economy is strongly related to agriculture, and the cropland areas over the country feed up to one billion of population. Thus, an effort has been made by Indian planners to use irrigation for reducing the dependence of agriculture on an erratic and unreliable southwest monsoon, which may be weak in some years, like 2002. Despite various problems faced in the harnessing of water resources and management of water, irrigation has emerged as the most effective measure to guard against the adverse effects of droughts and dry spells on crop products. The construction of canal irrigation in an area aims essentially at increasing both crop production and subsequent economic development. Simultaneously, it also brings out considerable changes in the environment and local ecosystems by the way of increased vegetation cover with improved vigor that affects the microclimate, especially in the arid and semi-arid regions where evapotranspiration exceeds precipitation (Douglas et al., 2006).

In the present study, we investigate the influence of LULC changes caused by the intensification and extensification of canal irrigation on surface heat and moisture fluxes in the arid and semi-arid regions of northwestern India (Rajasthan state), using long-term ground datasets, satellite observations and re-analysis. In addition, the present study examines the changes in number of rainy days, rainfall amount and aerosol loading and their possible association with the LULC changes.

2. Study area

Rajasthan (23°4′–30°11′ N, 69°29′–78°17′ E) is the largest state in India with a geographical area of 34.22 million ha (Fig. 1). The regional climate varies from semi-arid to arid with average annual rainfall ranging from ~480 mm to 750 mm with low values (~150 mm) in the western arid region and ~1000 mm in south-eastern plateau. Pre-monsoon (April–June) is the hottest season of the year with temperature varying from 32 °C to 45 °C. In western Rajasthan the air temperature often rises up to 48 °C and the prevailing westerly winds cause dust storms locally known as "Andhi". During monsoon season (July–September), the area receives ~90% of the annual rainfall; however, it often suffers from frequent drought due to poor and delayed monsoon rainfall, abnormally high summer-temperature and insufficient water resources. As a consequence, the arid environment of Rajasthan has been the subject of studies dealing with remote sensing and Geographic Information System (GIS) monitoring of the quantitative modeling of ground water recharge (Bhuiyan et al., 2009a), vegetation indexes and drought dynamics (Bhuiyan et al., 2006) and water stress (Bhuiyan et al., 2009b). The major part of the state is an arid region comprising 12 districts located in western and north-western parts accounting for 61% of the total hot Indian arid zone. The forest area accounts for 7.44% of the state with the major forest types to be the tropical dry deciduous forest and tropical thorn forest. The Indira Gandhi canal (IGC) project is one of the biggest canal projects in India, initiated on 31 March, 1958 with the aim to convert 0.15 million ha of semi-arid and arid desert wastelands to agriculturally productive areas. IGC covers seven districts of western Rajasthan namely, Barmer, Bikaner, Churu, Hanumangarh, Jaisalmer, Jodhpur and Sriganganagar. The project has resulted in the improvement in agricultural production and regional development transforming the barren deserts of western Rajasthan into rich and lush fields.

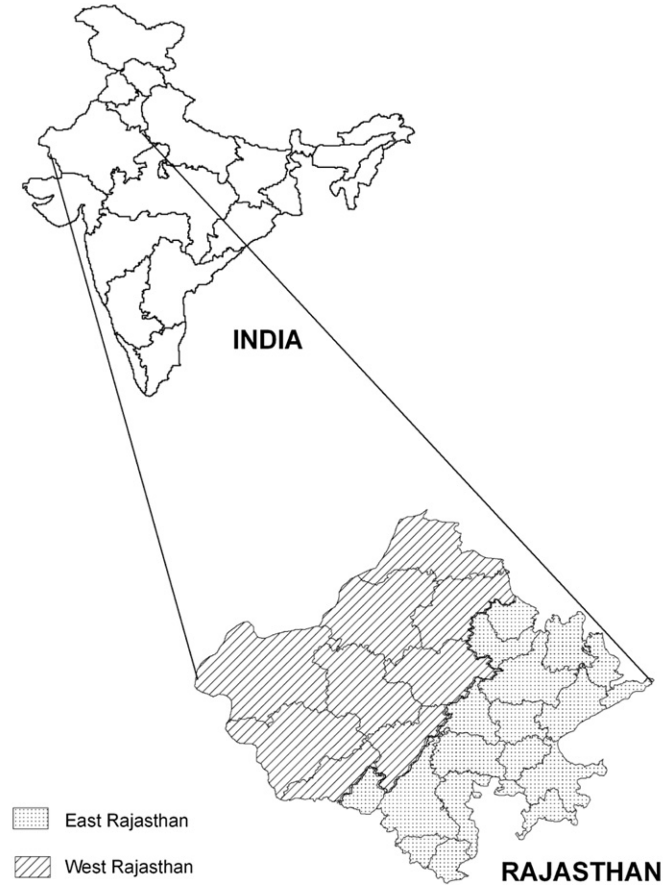

Fig. 1. Location map of the study area.

3. Datasets and methodology

3.1. Rainfall data

Information on spatial and temporal variation of rainfall is essential in understanding the hydrological balance on a global/regional scale. Daily gridded rainfall data with a 1° × 1° spatial resolution obtained from the Indian Meteorological Department (IMD) (Rajeevan et al., 2006) were used over the Rajasthan state. The IMD product uses gauge data from 1803 stations to estimate accumulated rainfall in the 24 h ending 08:30 IST (03:00 UTC)