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Inferring anthropogenic trends from satellite data for water-sustainability of US cities near artificial reservoirs

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ABSTRACT

Anthropogenic activities affect the water cycle and water supply at global and regional spatial scales, and approaches to water management must consider anthropogenic inputs. One of the major inputs in local-to-regional availability of water and the water cycle is land use land cover change as a result of urbanization, artificial reservoirs, and irrigation activity. To understand evolving trends in local hydrologic cycle for water sustainability of growing cities, this study employed a multi-factorial approach involving population trends, water use (and demand), streamflow, and various satellite-derived water-relevant variables. These variables are daily precipitation (from Tropical Rainfall Measuring Mission-TRMM, 3B42.V7), Normalized Difference Vegetation Index (NDVI) (from Moderate Resolution Imaging Spectroradiometer-MODIS-MOD13A1), land surface temperature (LST) (from MODIS-MOD11A2), and land cover (MODIS-MCD12Q1). Long term trends in such data were used to understand temporal and spatial trends in impounded watersheds hosting a large and growing city. The cities studied for water sustainability were Atlanta, Georgia and Buford dam; Columbia, South Carolina and Saluda dam; Columbus, Ohio and Alum Creek dam; Montgomery, Alabama and Jordan dam; Tulsa, Oklahoma and Keystone dam; and Tuscaloosa, Alabama and Tuscaloosa dam. Our study reveals that daily mean stream flow has been decreasing in all but one (Tulsa) of the areas selected. Satellite data trends between 2000 and 2012 showed a steady decrease in precipitation and NDVI, while LST has gradually increased. We attribute the NDVI (i.e., gradual decrease in vegetation cover) to LST rather than precipitation trends. The results of this research suggest that future temperature projections from climate models can be used in understanding vegetation activity and water availability over the study areas. Cities with larger upstream watershed area are potentially more sustainable and resilient (than those with small watersheds) as a result of spatial variability of water resources' response to climate change. Inter-basin water resources transfer is a possible solution to vulnerable cities in the future. The study results also emphasize the need to establish a sustainable and resilient water resources management system that includes narrowing the information and perception gap between the engineering community and the general public.

1. Introduction

Land use land cover (LULC) change can affect local and regional weather and climate (Mahmood et al., 2010, 2014; Kalnay and Cai, 2003; Pielke et al., 2002). The relative role of LULC change compared to other drivers is dependent on temporal and spatial scales and the geographical location. For example, a study by Zhang et al. (2007) showed the impact of human activities on precipitation from the geographical location aspect by considering different latitude bands. The trend of mean precipitation had increased in the mid-latitudes and decreased in the subtropics/tropics of the Northern Hemisphere, while the subtropics/deep tropics in the Southern Hemisphere experienced an increase. Changes in LULC are primarily responsible for change in the land-atmospheric interactions (e.g., Gibbard et al., 2005; Zhao et al., 2001). In an extended view of the changes in these interactions, the two components of water resources management – supply and demand – are affected both spatially and temporally (Schroeter et al., 2005).

There is a feedback (positive or negative) relationship between water supply/demand, population, urbanization, land use land cover change, and climate change (Fig. 1). Water supply and demand can be interpreted using socioeconomic factors and climate (e.g. Alcamo et al., 2007). However, it can be argued that water '*availability*' is prominently the driving factor for present/future '*supply*,' while '*demand*' is driven by demographic and socioeconomic factors. For irrigation alone, water withdrawal will increase by 11% (14% in developing countries and 12% in developed countries) by the year 2050 (Nachtergaele et al., 2011).

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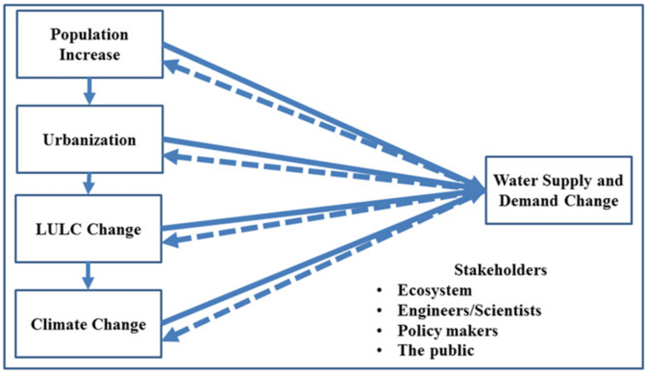

Fig. 1. Interconnection between population, land use land cover, climate, and water resources. The effect of one component on the other and hence the whole system is important for future sustainablity.

Artificial reservoirs, which are the result of dam construction, are one of the major components of LULC changes that can be drivers for irrigation practice, urbanization, and upstream inundation. Extreme precipitation and flood patterns have been known to change in impounded watersheds as a result of such LULC changes (e.g., Yigzaw et al., 2012, 2013; Yigzaw and Hossain, 2014; Woldemichael et al., 2012). This change (which can be an increase or a decrease) has also been demonstrated on probable maximum precipitation (PMP), for example by Rousseau et al. (2014), Stratz and Hossain (2014), Kunkel et al. (2013), and Woldemichael et al. (2014), using climate model results and future changes. Sustainability of water resources in the context of LULC and climate change is therefore challenging as water availability and demand are dynamically changing. A new concept of resilience and water management awareness has to be followed to alleviate the challenges to water sustainability of cities. This can be achieved through new engineering design and policy making.

Water conservation, recycled water use, conflict resolutions, and cultural changes should be part of the sustainability process (e.g., Pahl-Wostl et al., 2008; Adger et al., 2005; Tompkins and Adger, 2004; Gleick, 1998; Smit and Nasr, 1992). Bridging the gap between scientists/engineers and the public (e.g., Somerville and Hassol, 2011; McBean and Hengeveld, 2000) is also a needed area of attention as a means of achieving sustainability. One focus area of water sustainability is a city where there is a continuous increase in demand for water due to population growth (Bloom, 2011; UNPD, 2011). Future population and urban areas increase have significant impact on water and other natural resources (e.g., McDonald et al., 2014; Seto et al., 2011, 2012).

Regardless of size, artificial reservoirs play an important role in water resources management. For example, small reservoirs can supplement large scale irrigation and other water supply through rainwater

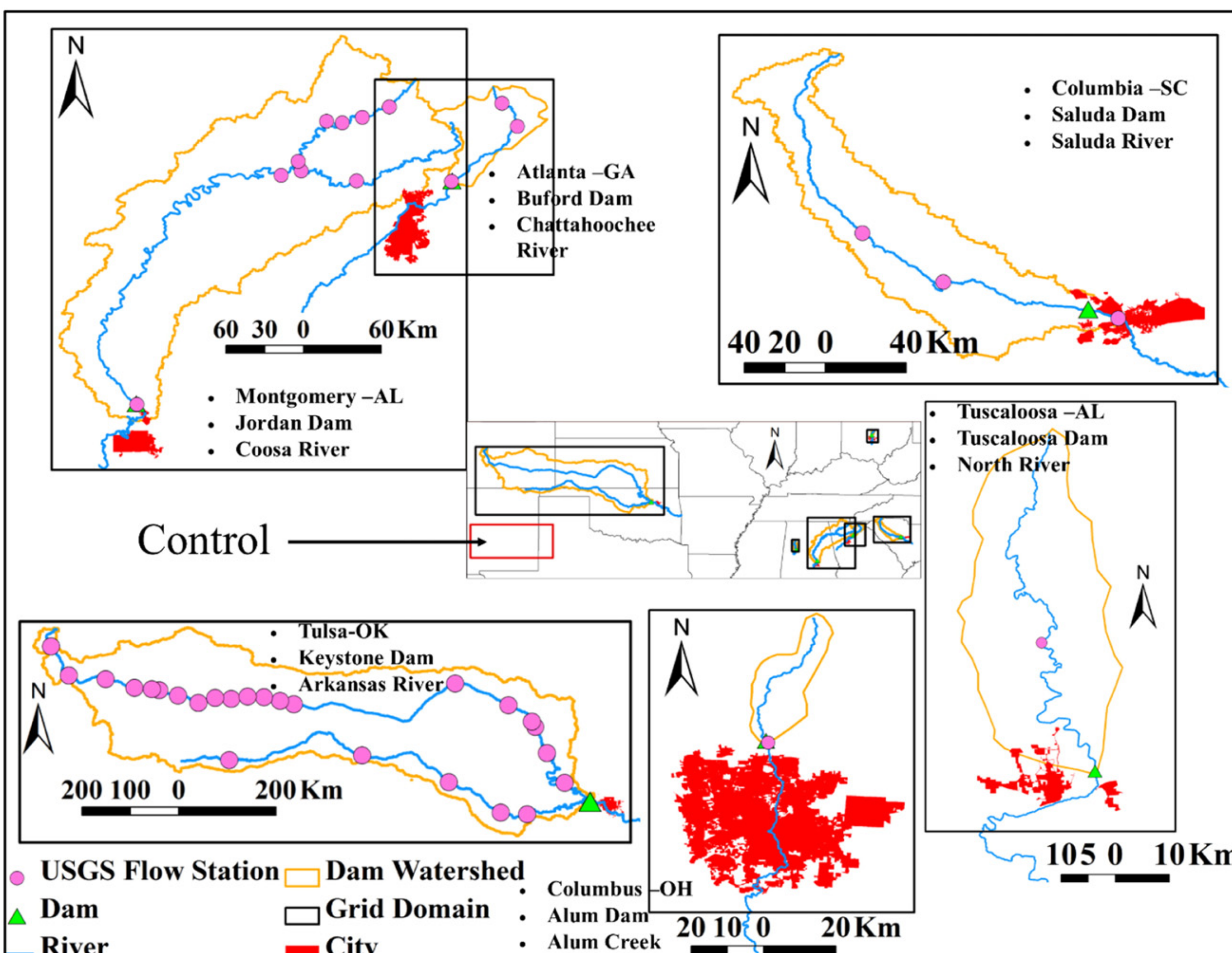

Fig. 2. Selected cities, dams, their watersheds and rectangular analysis domain.