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Geospatial analysis of land use change in the Savannah River Basin using Google Earth Engine

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ABSTRACT

Climate and land use/cover change are among the most pervasive issues facing the Southeastern United States, including the Savannah River basin in South Carolina and Georgia. Land use directly affects the natural environment across the Savannah River basin and it is important to analyze these impacts. The objectives of this study are to: 1) determine the classes and the distribution of land cover in the Savannah River basin; 2) identify the spatial and the temporal change of the land cover that occurs as a consequence of land use change in the area; and 3) discuss the potential effects of land use change in the Savannah River basin. The land cover maps were produced using random forest supervised classification at four time periods for a total of thirteen common land cover classes with overall accuracy assessments of 79.18% (1999), 79.41% (2005), 76.04% (2009), and 76.11% (2015). The major land use change observed was due to the deforestation and reforestation of forest areas during the entire study period. The change detection results using the normalized difference vegetation index (NDVI) indicated that the proportion areas of the deforestation were 5.93% (1999–2005), 4.63% (2005–2009), and 3.76% (2009–2015), while the proportion areas of the reforestation were 1.57% (1999–2005), 0.44% (2005–2009), and 1.53% (2009–2015). These results not only indicate land use change, but also demonstrate the advantage of utilizing Google Earth Engine and the public archive database in its platform to track and monitor this change over time.

1. Introduction

Land use/cover change detection can identify potential environmental events associated with rapid urbanization, forest conversion, and agricultural expansion (Drummond and Loveland, 2010; Agaton et al., 2016). Land use change is an indicator of the human footprint which can cause a loss of biodiversity and land degradation (Butt et al., 2015). Assessment and monitoring of land use change are essential for setting up integrated land and water resources management strategies (Badjana et al., 2015; Zhang et al., 2016).

Many studies have focused on identifying and examining the consequences of land use change over time. The influence of the land use change varies from one location to another due to geographic location and scale. Conversion of land from forested/agricultural to urban/suburban uses degraded aquatic ecosystems in the upper Piedmont physiographic region of South Carolina, with the change being particularly destructive during the actual land conversion process (Schlautman and Smink, 2008; Hur et al., 2008; Sciera et al., 2008). Another study in Heihe River Basin of Northwest China, revealed that land use change over time induced slight reductions in surface runoff, groundwater discharge, and streamflow (Zhang et al., 2016).

Forests have been recognized for their environmental benefits, such as water and forest product supply (Sun and Vose, 2016). For example, forests improve stream quality and watershed health by reducing the amount of stormwater runoff and pollutants that reach local waters (Schlautman and Smink, 2008; Hur et al., 2008; Sciera et al., 2008). Over half of the water supply in the U.S. flows from forest lands (Brown et al., 2008; Sun and Vose, 2016).

Forest disturbance over time can be visualized and documented using current remote sensing and geospatial techniques. For example, Cohen et al. (2016) studied forest disturbance across the conterminous United States from 1985 to 2012 and reported that national rates of disturbance varied between 1.5% and 4.5% of the forest area per year and were primarily affected by the forest harvest cycle in heavily

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forested regions. Huang et al. (2010) identified stand clearing disturbance events (harvest, fire, and urban development) by using an automated algorithm based on Landsat time series. Kennedy et al. (2010) conducted a study of forest disturbance in the U.S. Pacific Northwest utilizing the yearly Landsat time series with a temporal segmentation algorithm (LandTrendr algorithm) to capture abrupt disturbance events (e.g., fire and harvest). Chen et al. (2006) studied the effect of the land cover change on terrestrial carbon dynamics in the Southern United States using annual land cover data from 1860 to 2003 and a spatially explicit process-based biogeochemical model which indicated that the primary pattern of land cover change in the area was from forests to agricultural land use.

The Savannah River basin in the Southeast region of the U.S. has been experiencing environmental change from anthropocentric activities (Twumasi and Merem, 2008; Merem et al., 2015). These changes have been documented in the Savannah River Basin Management Plan for the Georgia portion of the Savannah River basin using satellite imagery and high-altitude aerial photography (The Georgia Department of Natural Resources, 2001). Twumasi and Merem (2008) studied the environmental change in the Savannah River basin and reported a decline in water bodies, vegetation, loss of harvested cropland, and farms. Merem et al. (2015) assessed the status of the environmental change in the Lower Savannah watershed in Georgia and South Carolina using temporal-spatial and environmental analysis and reported change in farm land use. Zhu et al. (2012) used a change detection algorithm to monitor forest disturbance at a high temporal frequency for the Savannah River site using Landsat 7 images.

There are various techniques used in analyzing land use/cover changes. Remotely sensed data holds an advantage in monitoring the detection of land cover change because of the large spatial coverage, high time resolution, and wide availability (Kennedy et al., 2009; Schneider, 2012; Vittek et al., 2014; Hu et al., 2016). Remote sensing has long been used for mapping and monitoring land use/land cover change over time (Skole and Tucker, 1993; Yang and Lo, 2002; Vittek et al., 2014; Huang et al., 2017). Despite the complications due to atmospheric disturbances, remote sensing can be used to identify and monitor land cover changes using multi-temporal satellite data and to study the relationship between the human influence on land cover and its consequences on the environment over time (Richter and Schläpfer, 2002; Butt et al., 2015).

In December 2010, Google launched a new technology named Google Earth Engine (GEE) (U.S. Geological Survey, 2010). This geospatial analysis platform made more than forty years of satellite imagery available online so that the scientists and researchers could analyze real-time changes to the Earth's surface (Houseman et al., 2015). Google Earth Engine has millions of servers around the world and has enabled the scientific community to analyze trillions of images using parallel processing (Dong et al., 2016).

The present study utilizes the advantage of the new geospatial technology of GEE and the historical record of Landsat satellite data to investigate the land use change within the Savannah River basin located in the southeastern United States. The specific objectives of this study were to: 1) determine the classes and the distribution of land cover in the Savannah River basin; 2) identify the spatial and the temporal changes of land cover that occurred as a consequence of land use change in the area; and 3) discuss the potential impacts of land use change in the Savannah River basin.

2. Study area

The Savannah River basin, designated by the U.S. Geological Survey (USGS) as a six-digit hydrologic unit code (HUC 030601), defines most of the boundary between Georgia and South Carolina, and has a small portion of its headwaters North Carolina (Cooke, 1936; Twumasi and Merem, 2008) (Fig. 1). The basin covers approximately 28,000 square kilometers (Twumasi and Merem, 2008). The Savannah River itself begins at the confluence of the Seneca and Tugaloo Rivers and flows southeast to the Atlantic Ocean (Anderson, 1993). There is a variety of different land covers present in the Savannah River basin with a large area along the river covered by deciduous forest and wetland (Zhu et al., 2012). Most of the study area is covered by evergreen forest and agriculture (Zhu et al., 2012). The modern-day Savannah River basin not only provides benefits such as hydropower generation, recreation, and flood protection (Lettenmaier et al., 1999), but it also provides a number of other important ecosystems services like the provision of wildlife habitat, recreational space, and the agricultural benefits (Anderson, 1993; U.S. Army Corps of Engineers, 2017). There are three major water reservoirs in the region: Lake Hartwell, Richard B. Russell Lake, and J. Strom Thurmond Lake, which are used for fish and wildlife management, hydropower, recreation, water quality, and water supply (Lattenmaier et al., 1999). The Thurmond Reservoir was used to cool the three nuclear reactor plants, but since their termination in 1990 the reservoir is mostly used for withdrawals for municipal, industrial, and agricultural use (Lettenmaier et al., 1999).

The basin is divided into three distinct regions: Blue Ridge province, Piedmont province, and Coastal Plain province (The Georgia Department of Natural Resources, 2001; Twumasi and Merem, 2008). The physiography of the area is the same as most of the Southeast U.S. and shows evidence of mountain formation in the Appalachian Mountains, as well as rising and declining sea levels in the coastal plain over geologic time (The Georgia Department of Natural Resources, 2001).

The climate of the Savannah River basin is divided into two regions: the coastal plain and the mountains. The coastal plain experiences hot summers and mild winters while the mountains experience mild summers and cold winters. The average annual temperature for the entire basin is 18 ° Celsius (The Georgia Department of Natural Resources, 2001). The average annual precipitation ranges from 1000 to 2000 mm per year coming mostly from rainfall with a small percentage coming from snowfall and snowmelt from the mountains in the upper basin (The Georgia Department of Natural Resources, 2001).

3. Data and methods

The land use change detection technique used in this study requires image preprocessing and normalization, the reference dataset, land cover classification, and derived change and no change detection layers. The land use change detection technique was applied and evaluated by developing code in the GEE platform using a supervised classifier algorithm and Landsat time series subsequently for each chosen year (Appendix E). High-resolution aerial imagery, available in GEE, was used as a reference layer for training and validating the classifications. Comparisons were made between the classified images for each study year to find locations where land cover changed. Subsequent analysis identified changed areas where deforestation and reforestation occurred. The general procedures are summarized in the flowchart illustrated in Fig. 2. In this figure, image preprocessing, land cover categorizing, and image classification are shown as step 1, and detecting land use change is shown in step 2.

3.1. Image preprocessing

Google Earth Engine facilitates a fast analysis platform by using Google's computing infrastructure. Pre-processed Landsat imagery available through GEE was used to assess land use/land cover change across the study area. Google Earth Engine provides online access to archived Landsat data as a collection of the USGS (Huang et al., 2017) (Table 1). All the Landsat data processing was conducted using the cloud-computing technology in the GEE platform (https://earthengine.google.org/). Landsat imagery scenes were used in this study for the years 1999, 2005, 2009, and 2015 (Table 1; Fig. 2) and were selected based on availability of high resolution aerial imagery for the study area in GEE. Simultaneously, two images were chosen for each year:

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