Remote Sensing of Environment 185 (2016) 186–197

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Assessing the role of climate and resource management on groundwater dependent ecosystem changes in arid environments with the Landsat archive

Justin Huntington [a,b,*,1], Kenneth McGwire [a], Charles Morton [a], Keirith Snyder [c], Sarah Peterson [d], Tyler Erickson [e], Richard Niswonger [f], Rosemary Carroll [a], Guy Smith [a], Richard Allen [g]

[a] Desert Research Institute, Reno, Nevada, United States
[b] Western Regional Climate Center, Reno, Nevada, United States
[c] USDA Agricultural Research Service, Reno, Nevada, United States
[d] Bureau of Land Management, Reno, Nevada, United States
[e] Google, Inc., Mountain View, California, United States
[f] U.S. Geological Survey, Menlo Park, California, United States
[g] University of Idaho, Kimberly, Idaho, United States

ARTICLE INFO

Article history:
Received 29 August 2015
Received in revised form 31 May 2016
Accepted 5 July 2016
Available online 20 July 2016

Keywords:
Landsat
NDVI
Cross-sensor calibration
Groundwater dependent ecosystems
Riparian restoration
Groundwater pumping
Phreatophytes
Complementary relationship
Evaporative demand

ABSTRACT

Groundwater dependent ecosystems (GDEs) rely on near-surface groundwater. These systems are receiving more attention with rising air temperature, prolonged drought, and where groundwater pumping captures natural groundwater discharge for anthropogenic use. Phreatophyte shrublands, meadows, and riparian areas are GDEs that provide critical habitat for many sensitive species, especially in arid and semi-arid environments. While GDEs are vital for ecosystem services and function, their long-term (i.e. ~30 years) spatial and temporal variability is poorly understood with respect to local and regional scale climate, groundwater, and rangeland management. In this work, we compute time series of NDVI derived from sensors of the Landsat TM, ETM+, and OLI lineage for assessing GDEs in a variety of land and water management contexts. Changes in vegetation vigor based on climate, groundwater availability, and land management in arid landscapes are detectable with Landsat. However, the effective quantification of these ecosystem changes can be undermined if changes in spectral bandwidths between different Landsat sensors introduce biases in derived vegetation indices, and if climate, and land and water management histories are not well understood. The objective of this work is to 1) use the Landsat 8 under-fly dataset to quantify differences in spectral reflectance and NDVI between Landsat 7 ETM+ and Landsat 8 OLI for a range of vegetation communities in arid and semiarid regions of the southwestern United States, and 2) demonstrate the value of 30-year historical vegetation index and climate datasets for assessing GDEs. Specific study areas were chosen to represent a range of GDEs and environmental conditions important for three scenarios: baseline monitoring of vegetation and climate, riparian restoration, and groundwater level changes. Google's Earth Engine cloud computing and environmental monitoring platform is used to rapidly access and analyze the Landsat archive along with downscaled North American Land Data Assimilation System gridded meteorological data, which are used for both atmospheric correction and correlation analysis. Results from the cross-sensor comparison indicate a benefit from the application of a consistent atmospheric correction method, and that NDVI derived from Landsat 7 and 8 are very similar within the study area. Results from continuous Landsat time series analysis clearly illustrate that there are strong correlations between changes in vegetation vigor, precipitation, evaporative demand, depth to groundwater, and riparian restoration. Trends in summer NDVI associated with riparian restoration and groundwater level changes were found to be statistically significant, and interannual summer NDVI was found to be moderately correlated to interannual water-year precipitation for baseline study sites. Results clearly highlight the complementary relationship between water-year PPT, NDVI, and evaporative demand, and are consistent with regional vegetation index and complementary relationship studies. This work is supporting land and water managers for evaluation of GDEs with respect to climate, groundwater, and resource management.

* Corresponding author at: Western Regional Climate Center, Reno, Nevada, United States
E-mail address: justin.huntington@dri.edu (J. Huntington).
[1] 2215 Raggio Parkway, Reno, Nevada, 89512.

http://dx.doi.org/10.1016/j.rse.2016.07.004
0034-4257/

1. Introduction

Groundwater dependent ecosystems (GDEs) rely on near-surface groundwater. They provide critical habitat for many sensitive species in arid and semi-arid environments and include phreatophyte shrub lands, meadows, spring areas, and riparian zones. Improved understanding of how climate and anthropogenic impacts affect the spatiotemporal variability of GDEs is needed to increase the effectiveness of ecosystem assessments, monitoring, adaptive management frameworks, and designations of protected areas (e.g. sage-grouse habitat). However, the lack of observations provides a constraint on the utilization of data for decision-making and scientific research. Long-term remote sensing observations from the Landsat archive have repeatedly demonstrated value for ecosystem monitoring, and are increasingly being used to evaluate GDE changes relative to changing climate, drought, groundwater pumping, and agricultural disturbance (Elmore et al., 2003; Groeneveld, 2008; Yang et al., 2011; Pritchett and Manning, 2012; Nguyen et al., 2014; Homer et al., 2015). The longevity and continuity of measurements from sensors in the lineage of Landsat's Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager (OLI), provide important baseline and current conditions that would not otherwise be attainable.

With free access to the Landsat archive, resource managers can now rely on long time series of Landsat derived vegetation index information in order to evaluate important factors affecting vegetation vigor within GDEs, including natural background variability due to climate, weather, land surface-atmospheric feedbacks, and anthropogenic factors such as land use, restoration, and groundwater pumping. However, long time series analysis with Landsat must deal with number of challenges, including data storage, computational efficiency, and changes in sensor bandwidths over time (i.e. TM, ETM+, OLI). The first two issues can be easily managed with parallelized cloud computing within Google's Earth Engine (EE), a powerful new cloud computing and environmental monitoring platform. The third issue of changing sensor bandwidths and accurate interpretation of Landsat vegetation index time series, requires quantification of how changing spectral response functions between sensors interact with the spectral variability of dynamic vegetation communities (Li et al., 2013). Effective quantification of GDE changes, and the credibility of derived resource management decisions, in part, depends on the compatibility of vegetation indices derived from different sensors, and the ability to isolate the effects of climatic and natural hydrologic variability on vegetation vigor from anthropogenic effects of land and water management.

2. Objective

The objective of this work is to 1) use the Landsat 8 under-fly dataset to quantify differences in spectral reflectance and vegetation indices between Landsat 7 ETM+ and Landsat 8 OLI for a range of vegetation communities in arid and semiarid regions of the southwestern United States, and 2) demonstrate the value of 30-year historical vegetation index datasets derived from sensors of the Landsat TM, ETM+, and OLI lineage for assessing GDEs in a variety of land and water management contexts. The study approach relies on sensor cross-calibration, cloud computing of Landsat and meteorological data, and statistical evaluation of vegetation index time series relative to annual precipitation and evaporative demand, restoration, and changing groundwater levels. Landsat 7 and 8 images from a brief under-fly test period are used to develop correction factors that account for differences between ETM+ and OLI, and to assess how discrepancies may be correlated with the typical spectral reflectance curves of dominant vegetation communities within the Great Basin, USA. Two forms of atmospheric correction are used to evaluate inter-sensor variability of spectral indices: 1) the at-surface reflectance products of Landsat climate data records available through the USGS Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA; USGS, 2015a), and 2) the Tasumi et al. (2008) atmospheric correction algorithm that utilizes meteorological datasets within EE. Time series of corrected Normalized Difference Vegetation Index (NDVI) are analyzed for six GDE study areas within the Great Basin to demonstrate the utility of the Landsat archive for local-scale GDE assessments.

3. Study areas and background

Specific study areas were chosen to represent a range of GDEs and environmental conditions important for three scenarios: baseline monitoring of vegetation and climate, riparian restoration, and groundwater level changes (Fig. 1 and Table 1).

3.1. Baseline assessment of vegetation and climate

Spring Valley (Fig. 2a) is located in eastern Nevada, and is of interest to federal, state, and local water resource and land managers due to the potential for groundwater development. State of Nevada groundwater permit terms, along with stipulated agreements by local and federal agencies, require detailed hydrologic and biological monitoring associated with groundwater development (NSEO, 2012; Burns and Drici, 2011; BWG, 2009). The alkali shrub phreatophyte area analyzed in this study is located in the southern portion of Spring Valley, and is a primary groundwater discharge area down gradient from proposed pumping wells. Depth to groundwater within the study area ranges from 2 to 10 m below land surface (Moreo et al., 2007). Phreatophyte shrubs obtain their water requirement from surface water, groundwater, or both, through root systems that range from shallow to 15 m depth (Robinson, 1958; Glancy and Rush, 1968; Dawson and Pate, 1996). While phreatophytes within the study area consume groundwater, they primarily rely on shallow soil water derived from precipitation, and typically only consume harder to access groundwater during summer and early fall when shallow soil moisture levels are low (Dawson and Pate, 1996; Chimner and Cooper, 2004), thereby making summer phreatophyte vegetation vigor (i.e. NDVI) a function of interannual precipitation, soil moisture, and shallow groundwater level variations.

Indian Valley (Fig. 2b) is located in central Nevada and is of interest to many wildlife and land managers due to the presence of the greater sage-grouse (*Centrocercus urophasianus*), a threatened species that has been petitioned for formal protection under the Endangered Species Act (DOI, 2015). Indian Valley has been identified as priority habitat due to its high sage-grouse lek (the male's mating arena) count, remote location, and relatively undisturbed phreatophyte meadow and shrub areas (BLM, 2012). An active area of cross-disciplinary research on sage-grouse is focused on the use of climate and Landsat archives to better understanding how climate, vegetation vigor, and sage-grouse habitat co-vary in time and space, and to identify which areas are resistant to prolonged drought (Aldridge and Boyce, 2007; Homer et al., 2015; Donnelly et al., 2016).

3.2. Riparian restoration

Maggie Creek (Fig. 3a) and Susie Creek (Fig. 3b), both located in north-central Nevada, are tributaries to the Humboldt River that support Lahontan cutthroat trout (*Oncoryhnchus clarki henshawi*). This species has been federally listed under the Endangered Species Act due to its sensitivity to changes in land and water use, prolonged drought, and changing climate (Williams et al., 2015). Vegetation communities within riparian zones of Maggie and Susie Creeks are typical of the Great Basin and include both obligate and facultative herbaceous and woody phreatophyte species. The Bureau of Land Management (BLM) collaborated with federal and local government agencies, non-profit organizations, and local mining and livestock companies to implement comprehensive watershed and riparian restoration efforts beginning in the early 1990s. Restoration efforts included