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Land surface temperature trends as indicator of land use changes in wetlands

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ABSTRACT

The impacts of agricultural expansion on wetlands are diverse and complex. Land surface temperature (LST) has a great potential to act as a global indicator of the status of wetlands and changes in their hydrological and evapotranspiration regimes, which are often linked to land use and cover changes. We use the whole MODIS LST archive (2000–2017) to perform time series analysis in the Kilombero catchment, Tanzania; a large wetland that has experienced major land conversions to agriculture during the last two decades. We estimated pixel based trends using three models: a seasonal trend model, and aggregated time series using annual means and percentile 90. We characterized the trends found by using land cover change maps derived from Landsat imagery and a post-classification comparison. The relation between Normalized Difference Vegetation Index (NDVI) and LST trends was also studied ($r = -0.56$). The results given by the seasonal trend model and annual means were similar ($r = 0.81$). Fewer significant trends were found using the percentile 90, and these had larger magnitudes. Positive LST trends (i.e. increasing) corresponded to deforestation and farmland expansion into the floodplain, while forestation processes resulted in negative LST trends. Moderate increases of LST in natural wetlands suggest that the impacts of human activities extend also into non-cultivated areas. We provide evidence of how time series analysis of LST data can be successfully used to monitor and study changes in wetland ecosystems at regional and local scales.

1. Introduction

Wetlands are multiple value ecosystems, providing a wide variety of services (Tiner et al., 2015). In some cases, wetlands are almost the only source of natural resources sustaining rural economies. Their plant communities have widely varying vegetation type, density and water demand and availability. Their water requirements and impacts on streamflows are complex and uncertain, and agriculture practices have a large impact on their functioning. Remote sensing imagery has been widely used for monitoring wetlands and provide spatially distributed and temporally frequent information on their environmental state (Jones et al., 2009; Amler et al., 2015; Guo et al., 2017).

Most monitoring approaches are based on bi-temporal land use land cover (LULC) change techniques, or on mapping the water surface dynamics with optical (Díaz-Delgado et al., 2016) or radar time series (Betbeder et al., 2015). Thermal infra-red data has been less frequently used, but it can nonetheless be essential to understand the spatial distributions of evapotranspiration in ground water dependent ecosystems. Land surface temperature (LST) based evapotranspiration estimations using thermal data have proven useful in practical applications in water management and water rights conflict solving (McVicar and Jupp, 1998; Anderson et al., 2012). It has been suggested that it is also possible to use LST variations to detect changes in land management practices, even when they are not associated with any direct change in land cover types (Luyssaert et al., 2014), or to map wetlands under aquatic vegetation (Leblanc et al., 2011). An additional advantage is that LST reacts to drought conditions earlier than Normalized Difference Vegetation Index (NDVI) (McVicar and Jupp, 1998).

A challenge encountered when using LST data is its high temporal variability; it greatly depends on climatic and illumination conditions, and measuring the change in LST between two single points in time is ecologically uninformative (McVicar and Jupp, 1998). Analyses of

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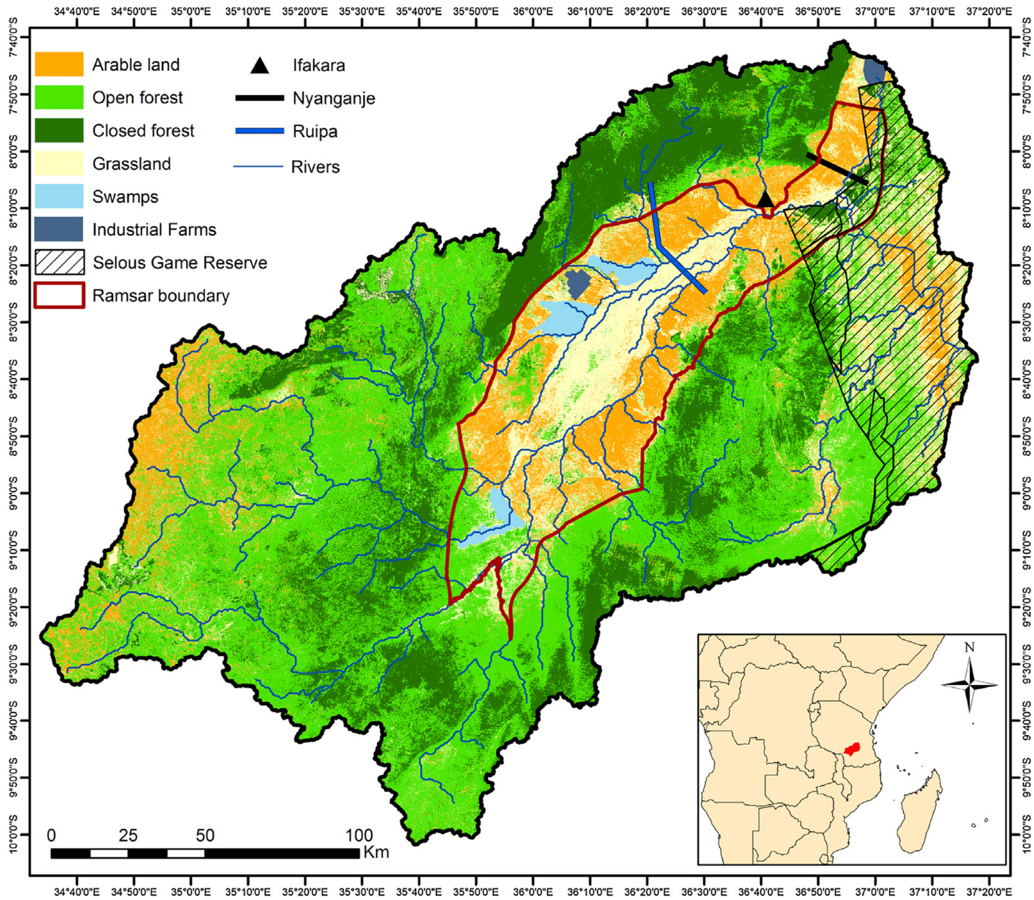

Fig. 1. Kilombero catchment with its main LULC classes. Ifakara, is the main urban center. The map also shows the Nyanganje and Ruipa wildlife corridors, modified from Wilson et al. (2017), and the Selous Game reserve.

dense LST time series can reveal landscape change trends affecting water balances and energy fluxes. This is especially relevant in highly dynamic and water dependent ecosystems such as wetlands. Despite having a coarse resolution (1 km), the daily MODIS LST products are ideal for time series analysis, providing daily LST data at global scale since 2000 (Neteler, 2010).

A second challenge to overcome when analyzing LST time series is separating the seasonal, gradual, and abrupt changes that are combined in time series data (Verbesselt et al., 2010; Ghazaryan et al., 2016), in addition to the noise generated by atmospheric effects. Time series analysis can be performed by extracting and aggregating the data into statistical parameters (Forkel et al., 2013), performing harmonic analysis (Verbesselt et al., 2010; Forkel et al., 2013), or applying change detection algorithms and unsupervised classification of the changes (Hecheltjen et al., 2014). Methods such as Breaks For Additive Seasonal and Trend (BFAST) (Verbesselt et al., 2010), BFAST-monitor (Verbesselt et al., 2012), or greenbrown (Forkel et al., 2013, 2015) have been developed to deal with such challenges. They analyze data decomposing it into three components: the seasonal variation, trend, and a remainder (Verbesselt et al., 2010). Break points caused by sudden changes in the land cover properties are flagged.

A third challenge is caused by the irregular time steps caused by gaps due to clouds and other effects that result in poor pixel quality and are flagged as such in the quality band.

The open source R package greenbrown has been designed to analyze trends, trend changes, and phenology events in gridded time series of vegetation indices interpolating missing values. These indices are indicative of vegetation cover and health status, and widely used in time series analysis to assess changes in vegetation (Yengoh et al., 2015; Ghazaryan et al., 2016; Forkel et al., 2013). However, due to the highly variable surface water dynamics of some wetlands, vegetation indices are less suited to study their long term trends. Decreases in NDVI can be a result of a loss of vegetation, or consequence of an increase in flooding. On the other hand, both decreases in vegetation cover and water content will produce increases in LST and vice versa. In spite of that, we find fewer examples of the use of LST to monitor long term changes. When LST is used for monitoring, it is often in combination with NDVI (Julien et al., 2011) or is mainly focused on climatology (Jiménez-Muñoz et al., 2016). The relationship between NDVI and LST has also been previously studied; when energy is the limiting factor NDVI and LST have a positive correlation, but when water is the limiting factor LST and NDVI are negatively correlated (Karnieli et al., 2010). To our knowledge, despite its well-recognized potentials, LST has not yet been thoroughly employed to analyze temporal trends in water based ecosystems.

The objective of this research is to investigate the potential of LST as indicator of land use changes using the Kilombero Valley as a study area. The Kilombero Valley is a large complex of wetlands that has experienced major land conversions to agriculture during the last two decades, and the consequences of such conversions are not well understood. The spatio-temporal variations of LST and NDVI in Kilombero were analyzed and assessed against these land conversions using the full MODIS archive (2000–2017) of LST and NDVI products and a set of Landsat-based LULC change maps. Three different time series models were compared (annual means, annual maxima and a seasonal trend model), and the existence of break points in the time series was explored.