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Patterns of land change and their potential impacts on land surface temperature change in Yangon, Myanmar

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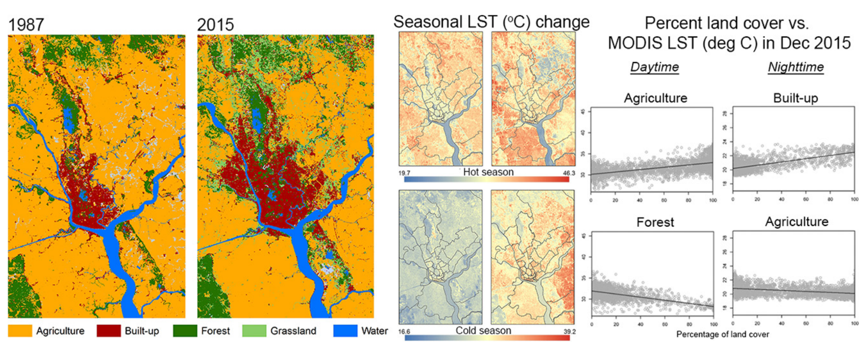
HIGHLIGHTS

- Urban expansion occurred along the prominent rivers of Yangon.
- Combining Landsat land/use cover and MODIS LST shed light on warming patterns.
- Agricultural land positively affected daytime LST the most.
- City core had higher nighttime LST than rural surroundings especially in cold seasons.
- Green and agricultural areas lowered nighttime LST regardless of seasonality.

GRAPHICAL ABSTRACT



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ABSTRACT

This study used remote sensing imagery to characterize land use/cover patterns and to derive land surface temperature (LST) of Greater Yangon, the largest urban agglomeration in Myanmar, to provide insights into the association between land use/cover and seasonal, daytime, and nighttime LST change. Analysis of Landsat images from 1987 to 2015 showed urban expansion radiating from the city center and along prominent rivers, with major increases in built-up land (6.4%) and grassland (10.1%) and consequent decline in agricultural land (17%). Examination of MODIS LST showed that agricultural land was warmer than the city core during daytime in hot seasons, while in cold seasons, the city core was warmer than its rural surroundings during both daytime and nighttime. Correlation analysis revealed stronger association between built-up land and nighttime LST from 2000 to 2015, suggesting an increased surface urban heat island effect. Furthermore, this study highlighted two main differences from prior work on the influences of land use/cover on LST. First, the predominant land use/cover type that had great overall impact on LST was agricultural land, marked by its statistically significant correlation coefficients across all time periods of analysis. Such finding emphasized the influence of agriculture and related practices on the atmosphere and climate system. Second, the temporal analysis of LST highlighted a stronger and more complicated role water played because of its negative correlations with daytime LST and positive correlations with nighttime LST. The findings of this study underscored more complex effects of land use/cover on the spatial and temporal variations of LST in Yangon, compared to prior work that generally reported high LST in the urban areas. These insights improve the understanding of the land change consequences on the temporal dynamics of LST and can support sustainable land use planning for the better well-being of the inhabitants in Greater Yangon.

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1. Introduction

Urbanization is one of the most visible anthropogenic forces on Earth (Dawson et al., 2009). It involves land use/cover transformations of replacing soil and vegetation cover by impervious surfaces, agricultural activities being replaced by commercial and industrial activities, and low-rise rural structures being replaced by high-rise complex urban structures (Pandey et al., 2014). The land transformations radically alter the aerodynamic, radiative, thermal, and moisture characteristics of the environment. These, coupled with the anthropogenic heat discharge of human activities arising from urbanization, have led to the urban heat island (UHI), a phenomenon of higher temperatures in urban areas than their rural surroundings, particularly at night (Arnfield, 2003). The implications of the UHI effects are diverse, including but are not limited to, increased heat stress and heat-related mortalities (Harlan et al., 2006; Hondula et al., 2012), increased energy and water consumption (Ewing and Rong, 2008; Gober et al., 2009), decreased air quality through the elevating emissions of air pollutants (Weng and Yang, 2006), and elevated risks of respiratory diseases and discomfort (Hondula et al., 2013). Given its multi-scale impacts, the UHI phenomenon has received considerable research attention in various environment-related fields, such as climatology, ecosystem ecology, urban planning, and sustainability (Chen et al., 2006; Estoque et al., 2017).

Research on the UHI has examined the urban and rural temperature differences using ground based instruments and remote sensing technology (Voogt and Oke, 2003; Roth, 2013). Ground based observations measure the UHI in urban canopy air temperature (e.g. Chow and Roth, 2006), but due to the uneven and sparse distribution of ground stations in some regions, they are limited in depicting temperature variability of large areas (Pandey et al., 2014). Remote sensing technology has the advantage of providing spatially explicit, area-wide, and up-to-date information on the dynamics of urban thermal environments (Lo et al., 1997; Berger et al., 2017). Thermal infrared remote sensing can be used to retrieve land surface temperature (LST), a well-recognized indicator for surface UHI (Roth et al., 1989; Tomlinson et al., 2011). To investigate the spatial and temporal patterns of the surface UHI, LST has been derived from various satellite images. For example, the Advanced Very-High-Resolution Radiometer (AVHRR) sensor data have been employed in earlier work (Balling and Brazel, 1988; Lee, 1993); the MODerate resolution Imaging Spectroradiometer (MODIS) LST data have been quantified (Tran et al., 2006; Pongrácz et al., 2010); the Landsat series of satellite imagery are probably the most commonly used (Aniello et al., 1995; Sobrino et al., 2004; Zhou and Wang, 2011; Estoque et al., 2017). Prior work has demonstrated the usefulness of remote sensing data for examining the variation of LST in relation to land use/cover (Lo and Quattrochi, 2003; Weng, 2003; Buyantuyev and Wu, 2010) and landscape structures (Zhou et al., 2011; Connors et al., 2013; Berger et al., 2017; Zhou et al., 2017), with the proviso of adequate cloud-free imagery and appropriate atmospheric correction algorithms. Studies have also compared between daytime and nighttime LST of different seasons (Buyantuyev and Wu, 2010) and investigated the temporal variability of the relationships between LST and land use/cover types (Zhou et al., 2014; Peng et al., 2016).

Globally, more people live in urban areas than in rural areas, with Asia being home to 53% of the world's urban population (United Nations, 2014). Continuing population growth and urbanization are projected to add 2.5 billion people to the world's urban population by 2050, and nearly 90% of the increase is estimated to concentrate in Asia and Africa (United Nations, 2014). The projected rapid population and urban growth suggest that the UHI effects in Asian cities will intensify, substantially affecting the quality of life of urban residents. Continuous efforts on examining the UHI phenomena are desirable because of their relevance in regional climate and human health.

Indeed, urban expansion and its impact on LST have been assessed for quite a few Asian cities over the last two decades (Weng, 2001; Chow and Roth, 2006; Tran et al., 2006; Zhou and Wang, 2011; Du et al., 2016; Estoque et al., 2017; Zhang et al., 2017). Research on this topic for Myanmar is, however, still lacking. The population of Myanmar has increased by 46%, from 35.3 million in 1983 to 51.5 million people in 2014 (Ministry of Immigration and Population, 2015). As Myanmar moves toward democracy, Yangon, the largest economic center and the former capital of the country, is experiencing rapid urbanization and accelerated development, putting pressure on the environment and the health of the society (JICA and YCDC, 2013). Recent attempts have delineated urban built-up areas (Lwin and Murayama, 2011, 2013), analyzed patterns of urban land changes, and predicted potential future urban expansion (Estoque, 2017). Nevertheless, long-term, spatially explicit monitoring of land change of the Greater Yangon and its adjacent areas, together with a comprehensive scrutiny of the impacts on the surface UHI, have not been conducted.

This study thus aims to examine patterns of land use/cover change of the last three decades in Yangon, Myanmar and their potential impacts on surface UHI. Specifically, the study uses remote sensing imagery to characterize land use/cover patterns and to derive LSTs of different time periods within the study area, so as to investigate the possible association between land use/cover and seasonal, daytime, and nighttime LST change. The novelty and scientific contribution of this study are twofold. First, from a methodology perspective, this study demonstrates a framework for integrating Landsat based land use/cover data of moderate spatial resolution with MODIS LST of finer temporal resolution to examine the impacts of land use/cover on LST. The combination of Landsat land use/cover and MODIS LST elucidates more novel insights into spatiotemporal variations in urban surface warming patterns than approaches with just Landsat or MODIS data alone. Second, in terms of area of analysis, Yangon provides a particularly intriguing case because the Myanmar economy is fast developing to a more commercial-based economy from a society based on agricultural production. The staggered transition from agriculture to built-up areas results in peri-urban surfaces at the margins of large "urban" built-up areas. Instead of confining at the city scale focusing on just built-up space, this study covers a larger area of urban surroundings that is societal relevant, to allow a better comprehension of the influences of different land use/cover types, particularly the agricultural land, on LST. Improved understanding of the consequences of land change on the temporal dynamics of LST can support sustainable regional land use planning and decisions about urban design that affect the well-being of the inhabitants in Greater Yangon.

2. Materials and methods

2.1. Study area

Located in Yangon Region, east of the Ayeyarwaddy River delta in Myanmar, the study area lies between approximately 16.566° to 17.192° N latitude and between 95.969° to 96.378° E longitude, covering 2934.58 km^2 (Fig. 1). The area has a tropical monsoon (Köppen *Am*) climate, with mean annual rainfall 2341 mm. Rainfall is highly seasonal, being concentrated in the southwest monsoon season between May and October; the northwest monsoon season between December and April is relatively cool and almost entirely dry (FAO, 2011). The average annual temperature is 27.4 °C, and April is the warmest month of the year, with an average temperature of 30.7 °C (WMO, 2017).

The study area covers Yangon Metropolitan Area, also referred to as the Greater Yangon in JICA and YCDC (2013), including Yangon City and parts of the six neighboring townships of Hlegu, Hmawbi, Htantabin, Twantay, Kyauktan, and Thanlyin. The Greater Yangon is the largest urban agglomeration in Myanmar, attracting a huge number of rural-urban migrants from all over the country (Yee et al., 2015). With a population of >7.3 million people, it is also the most densely populated region in Myanmar (Ministry of Immigration and Population, 2015). The