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Linking major shifts in land surface temperatures to long term land use and land cover changes: A case of Harare, Zimbabwe

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ABSTRACT

Rapid urban development is known to increase a landscape's thermal values, exposing residents to among others adverse heat related health impacts, discomfort as well as energy and water demand. Therefore, there is need to determine the implication of the transforming urban landscapes on urban micro-climate to optimise urban land uses and to effectively mitigate adverse impacts. In this study, we aimed at assessing micro-climate forcing of Land Use and Land Cover (LULC) changes in the heterogeneous Harare Metropolitan City, Zimbabwe, between 1984 and 2015. To achieve this objective, the transformation of major LULCs within the city was determined and relative brightness temperature used to assess long-term thermal changes in the city. Results show that coverage of high density residential areas increased by 92% between 1984 and 2016 at the expense of cooler green-spaces, which decreased by 75.5%. This translated to a 0.98 °C and 1.98 °C temperature increase, attributed to LULC changes alone and to all factors that include greenhouse effect and ozone depletion respectively. Results also show that converting bare areas to water bodies reduced surface temperatures by 4.5 °C, while the construction of low-to-medium density residential areas reduced bare surface temperatures by 3.78 °C. Conversion of green-spaces to low-medium residential areas increased temperatures by 0.16 °C. Overall, conversion of LULC types contributed more than 0.5 °C thermal elevation within the city, largely attributed to increases in built-up areas and reduction in heat mitigating green-spaces. These findings offer insight

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into landscape surface energy balance changes arising from urbanization, critical for urban planning, environmental governance as well and climate change management in cities.

1. Introduction

Rising temperature and climate change have become a concern in the recent decades (Nayak and Mandal, 2012; Hartmann et al., 2013; Chagutah, 2010). Rising temperatures lead to heat stress and increase in vector-borne diseases such as malaria and cholera, which may cause morbidity and mortality to vulnerable persons in society (Newland, 2011; McMichael and Confalonieri, 2012; Tanser et al., 2003; Simone et al., 2011). Furthermore, an increase in urban temperatures causes accumulation of smog and deterioration of air quality, increases discomfort, affect work performance as well as outdoor and indoor activities and increase energy and water demands (Goshayeshi et al., 2013; Mazon, 2014; Mohan et al., 2014; De-Azevedo et al., 2015). Therefore, understanding the implication of urban transformation on urban thermal change is necessary for mitigation of adverse impacts, urban planning, policy formulation and sustainable urban growth.

The observed and projected temperature intensity in Urban Heat Islands (UHI) can be attributed to natural phenomena that include the 60 year solar and thermohaline circulation. Such intensity can also be attributed to anthropogenic activities that include rise in atmospheric greenhouse gases and landscape transformations (Loehle and Scafetta, 2011; Hartmann et al., 2013). Urbanization alters energy and water balance, resulting in higher temperatures at the city core and lower temperatures towards the urban fringe and rural areas (Nayak and Mandal, 2012; Ward et al., 2014; Sertel et al., 2011). Hence, there is need to determine the implication of urban growth on urban temperatures, particularly in developing countries where resources for adaptation and mitigation are largely limited. Whereas in situ observations offer accurate data for analysis of temperature trends, they have limited spatial coverage, making it expensive to achieve desired coverage especially in developing countries. These countries often have low station density, inadequate for interpolation to map thermal distribution in heterogeneous urban landscapes (Barrett et al., 2007). Conversely, remote sensing offers low cost archival data at relevant spatial resolution valuable for understanding the relationship between LULC and their respective thermal characteristics (Sithole and Odindi, 2015; Owen et al., 1998). Landsat imagery data series for instance offers thermal and optical data dating back to 1972 free of charge (Gusso et al., 2014; Tao et al., 2013). However, despite availability of such datasets, their adoption in understanding the nexus between urbanization and climate change, particularly in African cities remains limited. Consequently, urban thermal elevation has mainly been associated with greenhouse gases and ozone depletion. Optical and thermal remotely sensed data therefore provide a unique opportunity for understanding the implication of LULC transformation on urban thermal characteristics.

Generally, previous studies that have analysed the relationship between long term changes in surface UHI and land cover changes have mostly used the difference between rural and urban temperature as a measure of UHI effect (Feng et al., 2014; Ogashawara and Bastos, 2012; Zhang et al., 2012). However, literature shows that comparing land surface temperature between rural and urban areas is not an effective method of quantifying UHI effect as rural areas around urban areas keep changing (Weng et al., 2007). Furthermore, long-term determination of rural/urban temperature differentiation for instance, considers combined thermal values for the entire urban landscape, dis-regarding the contribution of the changing LULC matrix and their thermal contribution to the UHI.

Feng et al. (2014) has recently suggested the use of different UHI indicators in determining long term effect of urban LULC transformation. As such, the relative brightness temperature has been proposed as an effective measure of UHI intensity, useful for monitoring shift in average temperature due to urbanization (Xu et al., 2013). The approach has numerous advantages which include computational simplicity and efficiency, as it is applied on brightness temperatures without emissivity correction. Hence this approach has been useful in determining the implication of LULC types on heat island intensities as well as their variations between season (Wu et al., 2012; Zhang et al., 2012). Zhang et al. (2012) for instance applied this approach to show the link between Normalized Difference Vegetation Index (NDVI) and urban heat island based on a single date imagery in Wuhan city, China. The unique potential and strength of the of the relative brightness